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INDIAN WHEAT RUSTS.

BY

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Imperial Mycologist;

AND

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WITH A NOTE ON

THE RELATION OF WEATHER TO RUST ON CEREALS.

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I.—INTRODUCTORY.[1]

The rusts of Indian cereals form the most important of the many diseases due to the attacks of parasitic fungi which damage the crops of this country. Not only on account of the actual loss annually produced, but also because of the importance of the grain as an article of food, no other diseases approach in their consequences to these.

Writing in 1892, the late Dr. Barclay, who devoted many years of his life to the group of fungi to which the rusts belong, said: "It is astonishing how little attention has been paid in India to this source, sometimes of enormous loss, and always, as appears probable, of considerable loss."[2] Since that time, however, the subject has come gradually into prominence, and two important papers dealing with it have appeared. One of these, published in 1896, by Drs. Cunningham and Prain[3] at Calcutta, contained the results of

[1] This section and some other paragraphs have been reprinted with slight alterations from "The Indian Wheat Rust Problem", Pt. 1, by E. J. Butler, Bulletin No. I, Dept. of Agric. in India, 1903, as this publication has now ceased to exist.

[2] Barclay, A. "Rust and Mildew in India". Journ. of Bot., Vol. xxx, 1892.

[3] Cunningham, D., and Prain, D. "A Note on Indian Wheat Rusts". Records Bot. Survey of India, Vol. i, No. 7, 1896.

investigations which they had carried out in that year on the distribution of the various rusts in Northern India, and the characters of the several fungi concerned. The other, written in 1897 by Dr. Prain[1] at the instance of the Government of India, gave a summary of the work done up to that date in the Australian colonies, where the rust in wheat question has attracted great and wide-spread attention, together with a *résumé* of the state of the rust problem at that time, translated from the German of Dr. Eriksson.

Both of these papers showed the need which existed for systematic and patient research before even the foundations of a rational knowledge of the rust question could be laid, much less the lines of treatment indicated. For there was no point brought forward more clearly than that the problem requires to be approached afresh in India, and cannot be dealt with from the standpoint of work accomplished elsewhere—a truism which is now recognised wherever the subject has attracted attention, that is, practically wherever wheat is grown. The conditions in one area are often so different from those which prevail in another, that the conclusions drawn from the one are to a great extent useless when applied to the other. Besides, even where the trained energies of many observers have been directed continuously for years to the one problem, as in Sweden and some other European countries, and in Australia, the solution is still far from being in view. Indeed there are few diseases of plants so obscure as this, and its difficulties, instead of diminishing, appear to increase with each succeeding advance of knowledge.

There is, then, in India the greatest need for information of a sort which can only be gained by patient and accurate observation carried on at many localities during the few months of each year when rust makes its appearance ; and this note has been prepared in the hope of exciting the interest of those whose opportunities permit them to join in the work.

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[1] Prain, D. "Rust in Wheat in the Australian Colonies", Agricultural Ledger, 1897, No. 16.

Dr. Barclay, in an attempt to estimate the annual loss from the rust of wheat in India, took, as a standard of comparison, one of the lowest estimates which has been made in any considerable wheat-growing country, namely, that of 1 per cent of the yield made by Mr. L. H. Bolley of the Indiana Agricultural Experiment Station, in the United States. On this basis he considered that the least loss occasioned by rust in India may be set down with comparative certainty at Rs. 40,00,000 annually, supposing that rust prevails throughout the wheat-producing areas of India. Sir George Watt held this figure to be much too low, and that the annual loss is very probably not far short of ten times as much, or 10 per cent of the yield; and this is probably nearer the correct figure. From the estimates of the Prussian Statistics Bureau in 1891, the loss in that year in the Prussian wheat harvest reached 31 per cent. This was a very bad year, but the annual loss probably exceeds 10 per cent in Prussia. In Australia the loss is considered to be from £2,000,000 to £3,000,000 per anuum. In England, in 1892, in answer to a circular from the Board of Agriculture, a number of farmers estimated their losses at from 9 to 16 bushels an acre, though that the average was considerably lower than this over the whole country is apparent from the fact that on 9 out of 37 of those farms from which answers were received no attack of rust was observed.

It is only by actual weighing of the produce of diseased against healthy plots that any accurate estimate can be formed, since the loss is often far greater than appears on the surface. Dr. Barclay, indeed, showed that the effects of the parasite were strikingly apparent when grain from a diseased ear was weighed against that from a healthy plant. As an average of several weighings he found that 10 healthy grains weighed as much as 30 diseased ones when the parasite was *Puccinia graminis*, and as 60 diseased grains when the parasite was *Puccinia "rubigo-vera."* The loss here in individual plants reached the enormous total of 66 and 83 per cent, according to the variety of rust present.

The fact that it is by no means rare in India to see the ground red under the stalks through field after field, from the shedding of the uredospores of the fungus, shows to what an immense figure the damage must mount from this loss of weight, since it means that where the appearance is noticed, scarcely a plant is free from the disease.

Probably, then, Rs. 4,00,00,000 is not above the annual loss to India from this source.

Probably every district where wheat is grown in India suffers more or less severely from the disease. We have either personally seen rust on wheat, or obtained specimens of it, from practically every important wheat-growing tract, from the Punjab to Bengal and Madras.

The rusts belong to a group of parasitic fungi, the *Uredineæ*, which are remarkable for possessing, when perfectly developed, four distinct phases in the life-history. These are characterised by four distinct forms, which, though belonging to the one plant, are often separated from one another by an interval of time, and sometimes require more than one host-plant for their successive development.

To understand fully the problem presented by the disease it is necessary that a brief account should be given of these four phases.

The first stage in the life-history of one of the wheat rusts may be taken as marked by the first appearance of rust-pustules on the growing wheat, an event which, in Northern India, usually happens in January or February. When a piece of wheat plant showing the first evidences of rusting is examined, it is found to be marked here and there by round, oval, or elongated raised patches of a reddish colour known as "sori". The fungus has existed, however, within the tissues of the plant for some time before the appearance of the sori, which are, in a sense, comparable to the fruit-capsules of higher plants. The fungus plant itself is composed of a ramifying body of threads occupying the spaces between the cells of the leaf or stalk, and consuming the nourishment

which, under ordinary circumstances, should go to feed these. When its development has reached a certain stage it bursts to the surface to form the sori. The particular position which these sori occupy differs to some extent in the different rusts. They are sometimes practically confined to the leaves, sometimes are found on the leaf-sheaths, culms, and even the ears as well. Each of them results from an accumulation of fungus-threads beneath the epidermis, which latter at first covers the sorus and prevents the contents from being seen. Later on the epidermis ruptures and exposes to view a yellow dust, consisting of thousands of spores, which have been formed from the tips of the threads at the bottom of the sorus. These are the uredospores. Their production occurs in myriads, and it is as a result of their shedding, after the rupture of the sori, that the ground under the wheat, in bad years of the disease, takes on its reddish colour.

The uredospore is a single-celled body with a double wall, provided with fine spines or teeth admirably suited for anchoring it to the object on which it has fallen. Its function is the rapid dissemination of the disease from plant to plant, by the agency of the wind. The wall is not of uniform thickness all the way round, but is provided with a certain number of thinnings or "pores" through which the germ-filaments push when the spore germinates. For the latter, all that is necessary is that the spore should, when ripe, fall into water or on to the surface of a plant moistened by rain or dew. That this is often the case, and that the plant is probably a wheat plant, is natural, considering the manner in which wheat habitually covers large areas continuously.

The germ-filament secures the further propagation of the fungus only when it encounters in its growth one of the stomata or air-pores of the wheat plant; otherwise it breaks up and dies rapidly. Having entered the stoma it ramifies through the substance of the plant, forming what is known as a "mycelium," or branched body of threads, between and around the cells, exactly like that which preceded the first

appearance of the sori. From this mycelium fresh uredo-sori may be produced, or the fungus may enter on its second stage of development, the teleuto-stage.

The teleuto-stage is characterised by the production of a second class of spores, the teleutospores. These are formed, as before, in sori, but the latter are black instead of being orange or yellow. In some of the rusts the teleutospores do not rupture the epidermis of the host-plant, while in others they do; but even when the epidermis ruptures, the spores are not, as a rule, shed in the same manner as the uredospores. They remain attached to the straw until harvested. In appearance they are quite different to the uredospores, for they are bicellular, with a much thickened wall, unprovided with spines. Their function is, in fact altogether unlike that of the uredospores, for they are not at all suited for wind-dissemination. They are resting spores, incapable of germinating, in most cases, for some time after their formation, even sometimes for many months. It appears, therefore, that the teleutospores are intended, naturally, to carry on the life of the species in the interval between successive crops of the host-plant; especially since they are the last of the rust elements to appear, coming out often up to harvest time. We will see, however, that it is doubtful how far they fulfil this function, and in India there seems to be particular reason to suspect that there is something still wanting to explain their utility.

Each species of rust has its own period of quiescence for the teleutospore. During this time it has, perhaps, lain on the field, or been ploughed in, or has been harvested and fed to cattle and returned again to the field in the form of manure. All these vicissitudes it can apparently undergo while keeping its power of germination unimpaired, at least as far as experience in other countries goes. Having accomplished its period of rest it germinates in the presence of moisture, putting out a filament through a pore; unlike the uredospore this filament quickly ceases its growth on having attained a

definite size. It does not form a mycelium, but, as the germ-filament represents one, it is known as a "pro-mycelium" and its formation indicates the third stage in the life-history of the rust fungus.

The promycelial stage is short. As soon as the filament ceases to grow, it divides up into segments, from each of which a minute stalk grows out laterally. On this a small ovoid spore is formed, quite colourless, and loosely attached on the stalk, so that it falls off readily and can be disseminated by the wind.

The next stage, that resulting from the germination of the promycelial spores, or "sporidia" as they are termed, requires, in the case of the rusts under consideration, to be passed on a new host-plant (termed the "intermediate host"), but is in some cases entirely unknown and very probably absent.

The connection between the black rust of cereals, *Puccinia graminis*, and the barberry plant has long been known. As far back as 1816, the yellow "cluster cups" of barberry rust had been shown to be connected with the rust of rye by a Danish schoolmaster named Schœler. His experiments were rough and remained unaccepted until 1864-65 when they were confirmed by de Bary, who produced barberry rust from wheat, and rye rust from barberry, under conditions of scientific accuracy. He made the remarkable discovery that when sporidia from a germinating teleutospore are sown on wheat they die, whereas if sown on the barberry leaf they germinate by putting out a fine filament which penetrates the leaf across the cell walls of the epidermis. The filament then grows and branches, forming a mycelium, and in ten days or a fortnight begins to collect into masses under the leaf-epidermis and again proceeds to form spores. This period of the life of the rust fungus, passed, in the case of the black rust of cereals, on the barberry, constitutes the fourth stage of its life-history.

The æcidial stage, so called from the production of æcidiospores on the intermediate host, was formerly considered to be a distinct fungus and called *Æcidium*. In the barberry its structure and life are shortly as follows. Where the leaf

has become infected by a sporidium from the teleutospores of black wheat-rust, it becomes thickened through a cellular hypertrophy so as to form a cushion-like swelling, on which are produced two different sorts of spores. The first of these, in chronological sequence, appears as tiny bodies of unknown significance termed spermatia, produced in vast numbers in small cup-like receptacles, the spermagonia, on the upper surface of the leaf. They need not be taken into account further than to remark that, though they have been seen once or twice to germinate like the other spores by sending out a filament, and in other cases to multiply like a yeast-cell, their subsequent fate and function is quite unknown.

A few days after the first appearance of the spermagonia the under-surface of the swollen areas begins to produce a second form of receptacle, of a golden-yellow colour, the well-known "cluster-cups." These are formed at first beneath the epidermis which they then rupture, turning back the edges and protruding the margin of a membranous-like receptacle, the pseudoperidium, which forms the sides and rim of the cup. Within this envelope the spores are produced. They are almost exactly like the uredospores, except that they are of a more golden-yellow colour and are often angular from pressure. They are disseminated by the wind, and germinate on falling into water by putting out a germ-filament, which, as de Bary discovered, can carry the fungus back to the tissues of the wheat plant in the stage with which we started in describing its complicated life-history. It has been found that the germ-filament of the æcidiospore dies unless it be formed on the surface of one of the cereals liable to black rust, such as a wheat plant, when it continues to grow, enters the plant through one of the stomata, and gives rise to a mycelium capable of producing uredospores and teleutospores on the wheat.

Were this cycle always to be carried out in its entirety, it is evident that the presence of barberry in the infected areas would be necessary for the recurrence of the disease. But it has long been known that the æcidial stage can be dispensed

with, for a time at least, though until quite recently the general opinion appears to have been that a passage through the intermediate host was occasionally necessary. Even this, however, would mean that the barberry should exist in the neighbourhood of the wheat fields, and that its total eradication should lead to the disappearance of this particular rust. But practical experience has shown that neither of these is the case. Moreover, black rust commonly occurs, even in Europe, many miles away from the nearest barberry, and is prevalent in Australia, where wild barberry is unknown and cultivated examples are not common. Dr. Cobb wrote in 1892, that up to that time the barberry *Æcidium* had never been seen in Australia. Yet rust had existed probably for years before this. In India the barberry is found only in the hills, hundreds of miles from some of the areas in the plains where rust is most severe and where *Puccinia graminis* has been found to be one of the causes of it. Not alone is it impossible in these cases for the barberry to play any part, but Eriksson has shown that the radius of infection in ordinary cases is not above 25 yards around the bush, and that hence the *rôle* of wind-borne æcidiospores from the barberry in connection with the disease has been immensely exaggerated.

The case with regard to the other rusts is quite parallel. Two of these are known on wheat in Europe, besides those which occur on other cereals but do not attack wheat. They are named *Puccinia glumarum* and *Puccinia triticina*. In neither case is an æcidial stage or an intermediate host known. If such exist they have not yet been discovered, and taking into account the minuteness of the search, their existence is at least problematical. In Australia *Puccinia triticina* occurs with *Puccinia graminis*, and here also an æcidial stage has not been forthcoming. This fungus was long confounded with the brown rust of rye, *Puccinia dispersa*, for which certain Boragineæ serve as intermediate hosts. Eriksson has, however, shown that the æcidiospores from these do not possess the power of infecting wheat.

Hence, so far as the three above-mentioned rusts of wheat are concerned, the presence of any intermediate hosts can no longer be considered a necessary factor in their cycle ; for even if other intermediate hosts exist, and remain yet to be discovered, it is quite certain that their presence is not essential, and that the disease can recur year after year without their intervention.

II.—PROPAGATION OF RUST FROM SEASON TO SEASON.

The problem of dealing with the rusts of cereals centres at present in one point, and until that point is elucidated we shall be groping in the dark in our attempts to find a solution. This is the determining of the mode by which the germs of the disease pass over from season to season.

The following possibilities must be considered : the disease may appear on the new season's wheat as a result of

1. Infection by the previous year's rust-spores from wheat, whether uredospores or teleutospores.
2. Infection from a "collateral" host, *i.e.*, from some other plant on which the rust is parasitic in the uredo-teleuto stages and on which it can live during the hot season, rains and commencement of the cold season (say from April to January).[1]
3. Infection from an "intermediate" host, *i.e.*, from some other plant on which the rust is parasitic in the æcidial stage and on which it can live during the same period (as the black rust, *P. graminis*, is known to do on the barberry).
4. Hereditary infection in the strict sense of the word, by means of a germ conveyed in the seed as has been suggested by Eriksson.

Another possibility has recently been mentioned by Klebahn of Hamburg.[2] Starting from the known facts of the remarkable dissemination of dust, sand and similar substances by

[1] This refers to the conditions which prevail in Northern India, particularly the United Provinces, but is capable with slight modifications of being applied to most of the wheat-growing parts of the country.

[2] Klebahn, H., "Die Wirtswechselnden Rostpilze," 1904, pp. 67-7 .

the wind, over thousands of square miles in some cases of which records have been obtained, he argues that rust spores may be similarly distributed to all parts of the world. For it is probable that there is no month of the year when rusted wheat is not growing in some region of the world, and hence uredospores from afar may be present in the atmosphere in a particular country, before the wheat of that country has itself become rusted.

As regards the first of these possibilities there is little to be said. Uredo infection is extremely unlikely in the plains of Northern India, for the wheat season here is exceedingly short as compared with that of Europe, and there is none in the ground between April or May and November. Therefore, any succession of rusted wheat plants all the year round, such as occurs in the case of *P. triticina* in the United States,[1] is impossible. "Volunteer" wheat, *i.e.*, wheat self-sown during or after the harvest, in Northern India is, so far as our experience goes, absolutely unknown. We have never seen any during the hot weather. If any plants do occur they must be rare, and it is scarcely conceivable to any one who has seen the onset of rust in a bad year that these few plants could serve as the source of infection. Besides we have not succeeded in producing rust artificially on plants grown in the open in the hot weather, and it remains to be seen whether the spores have power to infect when exposed to temperatures exceeding 100° F. as they are over most of the country for some months. Marshall Ward[2] has shown that in the case of an allied fungus, *P. dispersa*, exposure to such high temperatures prevents the germination of the uredospores. The localities in which we have chiefly studied the disease are situated in the Indo-Gangetic plain, one of the hottest zones in India. Those who have not experienced the fierce heat of the early summer months in this part of the world can scarcely appreciate

[1] Carleton, M. A., "Cereal Rusts of the United States," 1899.

[2] Marshall Ward, H., "On the Relations between Host and Parasite in the Bromes and their Brown Rust, *Puccinia dispersa* Erikss." Annals of Botany, 16, 1902.

the difficulty of believing that uredo infection carried on from plant to plant can possibly account for the annual outbreak of rust. The maximum day shade temperature remains above 100° F. for weeks at a time, and the surface of the soil is naturally exposed to a much higher temperature than this. The following table shows the effect of moist heat on the germination of the uredospores of *Puccinia glumarum* and shows that their thermal death point in five minutes is somewhere about 45° C. or 113°F. We have been unable to obtain germination of these uredospores after exposure to strong sun for some hours at a time when the shade temperature was about 95°F.

Germination of uredospores of P. glumarum after soaking in warm water for five minutes.

I.—FEBRUARY 22ND, 1905.

Temp. of water.	Germination in 24 hours.	Germination in 48 hours.
30° C. ...	good	good
35° C. ...	,,	,,
40° C. ...	poor	poor
45° C. ...	none	very slight
50° C. ...	,,	none
55° C. ...	,,	,,

II.—APRIL 1ST, 1905.

Temp. of water.	Germination in 24 hours.	Germination in 48 hours.
30° C. ...	good	good
35° C. ...	slight	,,
40° C. ...	,,	,,
45° C. ...	none	two or three spores germinated
50° C. ...	,,	none
55° C. ...	,,	,,

So also infection can scarcely result from uredospores lying in the ground from the previous year; for besides the fact that we have failed to get such spores to germinate after a lapse of a few months, the rust would appear at least a month earlier than it does, were such the case. The incubation period for the uredospores is about ten days and very rarely exceeds a

fortnight from the time of inoculation. Some spores would certainly germinate if the conditions happened to be favourable when the wheat is coming up, and would infect the young plants. Artificial infections show that even the first opened leaf is susceptible to the attack of rust. Hence we should look for rust in December, or in early years even earlier, whereas in Cawnpur it rarely appears before January.

Infection from the last year's teleutospores is perhaps possible ; but it is supported by no evidence since attempts to produce it artificially have failed, while the evidence against it accumulates from year to year. All the rust fungi known whose æcidial stage is passed on a different plant to that which bears their teleutospores, follow the same rule. Their teleutospores on germination give rise to sporidia which cannot attack the plant from which they came, but can only infect the "intermediate" host. The experiments have been many, and up to the present all of those which are free from suspicion point to the conclusion that the teleutospores of such fungi cannot on germination infect the same species as that on which they were formed. Besides *P. triticina* in India appears frequently, even perhaps habitually, to form no teleutospores.

As regards the second possibility, that of collateral infection, we have been at considerable pains to obtain all the rusts which could be found on other plants within the wheat area. The list is still very fragmentary, but it is unlikely that any common species in the vicinity of the wheat fields in certain districts has been omitted. Very few grasses have been found to bear any of the wheat rusts. *Festuca gigantea*[1] bearing *P. graminis* was found by Dr. Barclay at Simla, *Phalaris minor* bearing *P. glumarum* at Dehra Dun and Hissar, and *P. glumarum* also has been obtained on *Brachypodium sylvaticum*, the specimens having been obtained in Simla in August

[1] There seems to be some doubt regarding the identification of this grass in Dr. Barclay's works. It was so named in the "Descriptive list of the Uredineæ occurring in the neighbourhood of Simla," Pt. II, 1889. In a later paper, however, it is stated that *P. graminis* occurs in Simla on a wild grass, probably *Brachypodium distachyum*, Roem. & Schult, and the barberry was successfully inoculated with it. (Trans. Linn. Soc., Vol. iii, Pt. vi, p. 234, 1891.)

1904. Direct experiment, the details of which will be found below, shows that *P. glumarum* can pass from wheat to *Phalaris minor*, though from the experiments it would appear that this only occurs occasionally. *Brachypodium sylvaticum* has not been tested in the same way, since the specimens had not been obtained during the wheat-growing season.

Still these grasses can scarcely account for even the one rust, *P. glumarum*. *Brachypodium sylvaticum* and *Festuca gigantea* are both Himalayan grasses, not found in the plains, and are therefore hundreds of miles away from many wheat-growing districts. *Phalaris minor* is said by Duthie to be a common weed on cultivated land in the plains,[1] but this refers to the Punjab and North-Western India. It is not mentioned amongst Bengal grasses in Prain's "Bengal Plants" and is therefore apparently absent from a large part of the rusted area. Our specimen was obtained from Hissar in the Punjab. Of a large number of grass rusts examined from the plains, no other example of the cereal rusts was found, and Sir George Watt was equally unsuccessful in collections made in the Central Provinces and Berar.[2]

The difficulties in examining the third possibility, infection from æcidiospores on an "intermediate" host, are more considerable. For whereas it is possible by morphological characters alone to exclude most of the rusts found on other plants in the uredo-teleuto stages from any connection with those of cereals, in the case of the *Æcidia* often experiment only can be relied on. For the *Æcidia* possess no characters by which, short of inoculation, their relationships to their *Puccinieæ* can be ascertained. However the relationships of many *Æcidia* are known, and the number of those occurring in the plains appears to be small. Practically only that which occurs on the common weed, *Launea asplenifolia*, and those of the different species of barberry in the Himalaya, require detailed examination.

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[1] "Fodder Grasses of Northern India." Roorkee, 1888.

[2] Watt, G. "Indian Fungi." Agricultural Ledger, 1895, No. 20, p. 55.

The *Æcidium* on *Launea asplenifolia*, a species described but not named by Drs. Cunningham and Prain,[1] occurs commonly throughout the greater part, and perhaps the whole, of the wheat-growing areas of Northern India. As a result of their field observations in an extensive tour, these authors held that there was considerable ground to suspect its complicity in the form of rust due to *P. triticina*. The *Æcidium* of this cereal rust is so far unknown. It appeared at least possible that it was to be found in the *Launea* fungus. The uredospores which occur on *Launea* in company with the *Æcidia* are indistinguishable from those of *P. triticina*, except that the germ-pores seem to be fewer in the former. It is true the teleutospores have proved, now that those of *P. triticina* have been found, to be quite different, but this was not known in 1896. It is not, indeed, in itself a serious objection to the connection of the *Æcidium* with *P. triticina*, for it is not without precedent to find an *Æcidium* and a *Puccinia* belonging to quite different fungi occupying a particular plant at the same moment. The *Æcidium* on *Launea* might therefore belong to the *Puccinia* on wheat, while the *Puccinia* on *Launea* forms a distinct species. But direct experiment, the only true test when the relationship of an *Æcidium* is in question, has failed to support this view. The following table gives the result of inoculations made in 1903 with the *Launea* rust. They were made for the most part on plants germinated and grown under aseptic conditions in calcium chloride drying towers as described by Ward.[2] As may be seen, none succeeded.

INOCULATIONS WITH THE ÆCIDIOSPORES AND UREDOSPORES OCCURRING ON LAUNEA ASPLENIFOLIA.

Date.	Spores used.	Inoculated on	No. of plants inoculated.	No. of plants infected.	Remarks.
Feb. 13th, '03 ...	Æcidiospores ...	Triticum vulgare ...	1	0	Spores germinating freely.
Feb. 14th, '03 ...	Uredospores ...	Triticum vulgare ...	1	0	Do.

[1] Cunningham, D., and Prain, D. "A note on Indian Wheat-Rusts," Records Bot. Survey of India, Vol. I, No. 7, 1896.

[2] Marshall Ward, H., "On Pure Cultures of a Uredine, *Puccinia dispersa* (Eriks.)" Proc. Roy. Soc., 1902.

INOCULATIONS WITH THE ÆCIDIOSPORES AND UREDOSPORES OCCURRING ON LAUNEA ASPLENIFOLIA—*contd.*

Date.	Spores used.	Inoculated on	No. of plants inoculated.	No. of plants infected.	Remarks.
Feb. 14th, '03 ...	Uredospores ...	Triticum vulgare ...	1	0	Spores germinating freely.
Feb. 14th, '03 ...	Uredospores ...	Triticum vulgare ...	1	0	A leaf "layered" in a watch-glass full of germinating spores.
Feb. 18th, '03 ...	Æcidiospores ...	Triticum vulgare ...	2	0	.....
Feb. 18th, '03 ..	Æcidiospores ...	Triticum vulgare ...	2	0	.....
March 11th, '03...	Æcidiospores ..	Triticum vulgare ...	1	0	Germination of spores very good.
March 11th, '03...	Æcidiospores ...	Hordeum vulgare ...	1	0	Do.
Dec. 27th, '03 ...	Æcidiospores ...	Triticum vulgare ...	3	0	.....
Dec. 27th, '03 ...	Æcidiospores ...	Triticum vulgare ...	3	0	.....
Dec. 27th, '03 ...	Uredospores ...	Triticum vulgare ...	3	0	.....
Dec. 27th, '03 ...	Æcidiospores ...	Hordeum vulgare ...	3	0	.....
Dec. 27th, '03 ...	Æcidiospores ...	Hordeum vulgare ...	3	0	.....

The *Æcidia* occurring on species of barberry in the Himalaya have been more than once referred to. The following species of *Berberis* are mentioned by Klebahn,[1] as having been stated to act as intermediate hosts for *P. graminis* in various countries: *B. vulgaris* L., *B. Lycium* Royle, *B. canadensis* Pursh., *B. nepalensis* Spreng., *B. aristata* D. C., *B. amurensis* Rupr., *B.* "*Neuberti Carolinæ*," *B.* "*atropurpurea*", *B. ilicifolia* Forst., *B. aristata* D. C., *B. altaica* Pall.

It is necessary, however, to mention that the *Berberis Æcidia* are often "specialised" forms (see below, Chap. VI.), belonging to the *Puccinia graminis* of one grass and not of others. Thus the *Æcidium* produced by teleutospores from barley can reinfect barley, rye, etc., but not wheat. That from oats can reinfect oats, but not wheat or barley, and so on. Hence the mere presence of the *Æcidium* of *P. graminis* on a barberry by no means indicates that wheat or barley can be attacked by its spores. As will be seen below a striking instance of this occurs at Simla.

Of the above, *Berberis vulgaris*, *B. Lycium* and *B. aristata* are said by Barclay,[2] to bear the *Æcidia* in the Simla Himalaya. Cooke[3] mentions the *Æcidium* also on a species of

[1] Klebahn, H., "Die Wirtswechselnden Rostpilze," 1904. p. 225.
[2] Barclay, A., Journal, Asiatic Soc., Bengal, Vol. lvi, Pt. ii, p. 367, 1887.
[3] Cooke, M. C., Grevillea, Vol. vi, p. 117, 1877.

Berberis from Simla and Massee[1] on *B. vulgaris* from Jaunsar. Barclay, however, remarks that it is not quite certain that all the three forms at Simla bear the same species of *Æcidium*. He considers that there can be little doubt that the species on *B. aristata* is *P. graminis*, though he did not confirm its relationship (by inoculation) with that fungus as it occurs abundantly on the jungle grass around Simla. He subsequently[2] produced spermagonia on *B. Lycium* with teleutospores from this grass, thereby proving that *B. Lycium* is the intermediate host for at least one of the forms of *P. graminis*. Still in spite of frequent searches he never found *P. graminis* on any cereal near Simla, except on one occasion when on a botanical excursion with Sir George Watt it was found in a wheat field at Muttiyana near Simla.[3] The barberry *Æcidia* there would hence appear to be ordinarily "specialised" forms not readily communicable to cereals, but in part at least connected with the above mentioned wild grass.

Æcidia were found in the course of our investigations by collectors in the Himalaya from Simla to Mussoorie on *B. vulgaris*, *B. aristata* *B. coriaria* Royle, *B. umbillata* Walt, and *B. Lycium*. On *B. asiatica* and *B. nepalensis*, which are common in this region, none were found.

The *Æcidium* on *B. Lycium* is extraordinarily abundant near Mussoorie . It is, however, as far as the Mussoorie specimens are concerned, not connected with *P. graminis*. It differs widely from the *Æcidium* of the latter, chiefly in the fact that it produces marked "witch's broom" malformations on the host plant. The same form was found on *B. aristata* and *B. coriaria*, in addition to *B. Lycium*, in Jaunsar. It is allied to *Æcidium Magelhœnicum* Berk., *Æ. graveolens* (*Puccinia Arrhenatheri* Eriks.) and *Æ. Jacobsthalii-Henrici* Magnus which are found respectively on *B. ilicifolia* in Terra del Fuega., *B. vulgaris* in Europe and *B. buxifolia* in Terra del Fuega and

[1] Massee, G. "Fungi Exotici, I" Kew Bulletin, 1898.
[2] Barclay, A., Transactions of the Linnean Society," Vol. III, Pt. 6, p. 234, 1891.
[3] Watt, G., "Indian Fungi." Agricultural Ledger, 1895, No. 20.

Chili. It has been named *Æcidium montanum* since it does not agree with any of the known species.[1] It is remarkable that *B. Lycium* should bear two entirely distinct *Æcidia* in localities so little separated as Simla and Mussoorie.

In the Mussoorie species two forms of fungus attack are found on *B. Lycium* and *B. aristata*, and probably on *B. coriaria* as well.

In the one (Plate V, Fig. 1), a whole or part of a shoot is affected, and all the new growth turns sharply upwards, thus developing what is known as "negative geotropism." Dwarf shoots crowded with tiny malformed leaves are produced at the nodes, and from them peculiar elongated succulent shoots nearly devoid of leaves or bearing only small or malformed ones are developed. The whole of the new growth usually is infested with the fungus mycelium, and æcidial cups are produced on the under surfaces of the leaves or on the shoots. It is a typical example of an internal perennial fungus mycelium, affecting all new growth from below, and not arising at the beginning of each season from infection anew by spores.

In the other form of attack (Plate V, Fig. 2), the leaves when mature are affected, and there is no deformity produced. Large patches, bearing *Æcidia*, come out on the under surface of the leaf. This appears to be the result of infection by spores and not of a perennial mycelium extending up from the tissues below. Intermediate states are common, and there is no doubt both belong to one and the same fungus.

It is only when the second form occurs alone, probably as a direct result of infection by spores from a neighbouring plant, that this species can be mistaken for the *Æcidium* of *P. graminis*. Even then it differs in the much greater length of the cups, which may reach to 4 mm. long, and in the area of the affected patches which are usually $\frac{1}{4}$ to $\frac{3}{4}$ inch in diameter. The size of the *Æcidium* of *P. graminis* is much less than this (Plate V, Fig. 3). The spores also of the latter species are smaller than those of the former.

[1] Butler, E. J., "Some Indian Forest Fungi," *Indian Forester*, 1905.

The following inoculations were made with spores of this *Æcidium* from *B. Lycium* obtained at Mussoorie, on wheat and barley grown in the Laboratory at Dehra Dun. The spores, while germinating freely at Mussoorie, did so badly at Dehra Dun which is some 4,000 ft. lower in altitude though only 12 miles distant. As in the case of the Launea fungus, none were successful. They were made on plants grown in pots or beds, since at the season at which they were carried out risk of infection by uredospores from wheat was absent.

INOCULATIONS FROM THE ÆCIDIUM OCCURRING ON BERBERIS LYCIUM AT MUSSOORIE.

Date.	Æcidiospores inoculated on.	No. of plants inoculated.	No. of plants infected.	Remarks.
May 24th, 1904 ...	Triticum vulgare ...	29	0	Temperature range in Laboratory 82° to 96° F.; germination of spores poor.
May 24th, 1904 ...	Triticum vulgare ...	37	0	
May 24th, 1904 ...	Hordeum vulgare ...	50	0	
May 24th, 1904 ...	Hordeum vulgare ...	49	0	
May 24th, 1904 ...	Hordeum vulgare ...	37	0	
June 28th, 1904 ...	Hordeum vulgare ...	.....	0	A small bed of plants grown under shade, out of doors, inoculated.
June 28th, 1904 ...	Triticum vulgare ...	.....	0	Do.

From Simla, in August 1904, *Æcidia* were obtained on *Berberis coriaria* Royle, *B. Lycium* Royle and *B. umbellata* Walt, presenting a much greater resemblance to that of *P. graminis*. These were clearly what Barclay had examined. No witch's broom malformation was visible, and the size of the spores, cups and affected patches more nearly approached to that species. Inoculation of cereals with the spores of this species has not, unfortunately, been possible owing to the distance from Simla and the difficulty of getting spores to germinate when brought down some 5,000 or 6,000 feet to a

temperature about 20°F. in excess of that of the locality where they were gathered. Since, however, as has already been mentioned, Barclay produced an *Æcidium* on *Berberis Lycium* in Simla by inoculating with the teleutospores of *Puccinia graminis* from a wild grass, it is probable that these Simla *Æcidia* all or in part belong to *P. graminis*. The above-named barberries are, therefore, the only intermediate hosts for any of the three rusts which attack cereals as yet discovered in India: and it appears probable that they only act as such in the Western Himalaya. At Simla the form of *P. graminis* concerned is a specialised one not connected with wheat. Only once could Barclay find wheat rusted from this rust near Simla, though it was ordinarily much rusted from the others, and though *P. graminis* was common enough on the *Brachypodium* grass. The one case found on wheat was probably an illustration of an interesting fact connected with these specialised forms. They are, under certain favourable conditions, able to extend their range and attack plants ordinarily immune. An instance will be found below where out of some 35 inoculations in which attempts were made to infect *Phalaris minor* with *Puccinia glumarum* from wheat only one succeeded. It has been shown in some cases that wounds, the attacks of aphides, etc., render plants ordinarily immune susceptible to certain fungi, and something of this sort may have happened in the case mentioned.

It can, perhaps, now be admitted that the search for intermediate hosts is not likely to result in any discovery of much practical importance. The rust fungi of several European countries are very completely known. Probably no order amongst fungi has been so thoroughly explored as this. Still *Æcidia* have not been forthcoming for two of the cereal rusts common in Europe as in India, *P. glumarum* and *P. triticina*; and we are forced to conclude that these two fungi are capable of dispensing altogether with the æcidial stage. Even the third of our rusts, *P. graminis*, for which an æcidial stage is known, as already said, on various barberries, is clearly capable

of existing without the intervention of this stage from year to year. That this is so in Europe is highly probable, as for instance in Bosnia and Herzegovinia where *Berberis* is almost absent.[1] That it is so in India is as certain as anything can be. The *Æcidium* of *P. graminis* has been unsuccessfully sought for in the Himalaya, east of Simla. *Berberis Lycium*, *B. coriaria* and *B. aristata* seemingly replace it by the witch's broom producing form in this region. It may occur on one of the other species, such as *B. vulgaris*, but east of Simla *B. vulgaris* is very rare or even, as we are informed by Mr. Drummond, I.C.S., who has kindly looked up the matter for us at the Herbarium of the Royal Botanic Garden, Calcutta, probably entirely absent. *B. asiatica* which comes down lower on the hills than the others appears to be free from any *Æcidium*. The Eastern Himalayan species have not been examined, but they are far away from the great wheat-producing provinces of North-Western India and may be ignored. The only barberries known in India proper between the Himalaya on the North and the Nilgiris on the South are *B. asiatica* (on which the *Æcidium* has not yet been found on Parasnath, a high hill in Bengal, and *B. aristata* on the higher summits of the Western Ghâts. The latter, which is given by Gamble in his "Manual of Indian Timbers," is not mentioned in Cooke's "Flora of the Presidency of Bombay," and probably occurs only on the higher ranges to the South. Yet at Nagpur, more than 500 miles from Parasnath, and at Khandwa, more than 600 miles from any of these hills, *P. graminis* was, at least in 1904, the prevalent rust. Indeed Barclay's observations and the tables given below show that, in ordinary years, *P. graminis* is commoner in the areas furthest from the habitats of the barberries, and *P. glumarum* commoner near the Himalaya. It is out of the question that the yearly appearance of this rust, which even in 1904, a year of little rusting, was found in almost every field in some localities in Central India, can be due to spores blown from these immense distances.

[1] Brandis, quoted by H. Zukal in Zeitschrift für Pflanzenkrankheiten, Vol. X, p. 20, 1900.

In the absence of any evidence in favour of the first three possible ways already considered by which rust may persist from year to year, the fourth possibility, that of the hereditary germ, requires special consideration.

This possibility, suggested years ago but only recently brought prominently forward by the work of Eriksson, has given rise to an animated controversy.[1] A very brief summary of that author's well known "Mycoplasm" theory is only possible here. The hypothesis was based in the first instance on a number of theoretical considerations supported by a mass of field observations extending over some ten or twelve years. It supposed that the rust fungi must, in the cereals specially liable to the disease, live for a long time in a latent condition in symbiosis with the protoplasm of the cereal in the cells of the plant itself, the combined plasma being known as "mycoplasm." Only a short time before the eruption of the first uredo-pustules when the external conditions are favourable does it enter on a visible state assuming the form of a mycelium. In his latest works this view has been supported by a certain amount of cytological evidence. Some cells of the susceptible varieties are found more or less filled with a peculiar dense protoplasm, the cell appearing to be otherwise quite normal. Later on changes occur in the cell nucleus. the fungus protoplasm becomes parasitic, passes out of the cells into the intercellular spaces and becomes what Eriksson terms a protomycelium out of which eventually the true mycelium is formed.

Though this requires independent confirmation before it can be accepted, and though Marshall Ward in England strongly combats Eriksson's theory as a whole, yet it appears to afford

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1 *Cf.* Eriksson, J. "Vie latente et plasmatique de certaines Uredinées," Compt. Rend., 1897, "Der heutige Stand der Getreiderosfrage" Ber. d. deusch. Bot. Gesellsch., Bd. XV, 1897, "Sur l' origine et la propagation de la Rouille de Céréales par la Semence," Ann. d. Scien. Nat. Bot. T., XIV and XV, 1901-2, "Ueber das vegetative Leben der Getreiderostpilze" I to IV, Kgb. Vete, Ak., Handl.. 1904-5, &c. Klebahn, H., "Die Wirtswechselden Rostpilze," 1904. Ward, H. M., "On the histology of Uredo dispersa Eriks, and the Mycoplasm Hypothesis"- Phil Trans., 1903, "Recent Researches on the Parasitism of Fungi", Ann. of Botany, 1905, etc.

a solution more in harmony with the observed facts than any other hitherto put forward.

That there is nothing inherently improbable in Eriksson's view is clear, since instances are known where two distinct plasmas, a parasitic and a host, are capable of existing in direct contact without the intervention of any visible membrane and without any detrimental effect on each other for at least a considerable portion of their mutual life.

In the course of some work carried out by one of us [1] several years ago, on the parasites of the aquatic fungus genera *Pythium* and *Saprolegnia*, some good examples were met with. Both these genera are subject to the attacks of the minute fungi known as *Chytridiaceæ*. One of these parasites was found on a species of *Pythium*. The parasite begins life as a tiny mass of protoplasm expelled from an asexual reproductive organ, termed a sporangium. It is capable of independent motion, swimming about in the water by means of a cilium. When one of these swimming spores comes to rest in the neighbourhood of a filament of *Pythium*, it attaches itself to the latter, rounds off, loses its cilium and surrounds itself with a wall. From the spore thus attached to the outside of the filament a tiny hollow process now grows out and pierces the filament-wall. This process then opens and the spore-protoplasm streams into the *Pythium*-protoplasm within the filament (Pl. 5, Fig. 4). Both plasmas are in direct contact, not separated in any visible manner. For a short time it is possible to distinguish the little drop of parasitic protoplasm surrounded by that of its host, since the former is more homogeneous and of higher refractivity. Soon, however, it disappears from view, not to appear again until its reproductive stage arises. For part, at least, of this time it can be brought to view by killing and staining, since its "nuclei" are somewhat different from those of the *Pythium*. Otherwise the next sign of its presence is the swelling up of the filament either at an end or in the middle, but

[1] Butler, E. J., "On *Pythium* and some *Chytridiaceæ*," Paper read before the Botanical Section, British Association, Bradford, 1900.

not necessarily at the spot where the parasite entered. The swelling resembles the normal spore-formation of the *Pythium* more or less closely. It is, perhaps, some hundreds of times bigger than the parasitic body which originally entered. When the full size is reached, it is cut off by walls from the filament on which it is borne, and soon matures as a sporangium of the Chytridian. From it, through an opening, large numbers of spores of the parasite identical with that with which we commenced, emerge and proceed to attack new filaments.

We have here, then, a case in which a parasitic plasma lives and moves within a host from whose plasma it is not separated by any visible boundary. Yet it retains its autonomy and comes to the surface to renew its independent life at the proper moment.

The last possibility which we have to consider is that suggested by Klebahn of the infection by spores from other regions of the globe. Though it is no doubt true that particles of matter weighing considerably more than a uredospore have, in certain instances, been rapidly carried for thousands of miles in the air, still it is extremely improbable that this is common. Many diseases including a considerable number of rusts are confined to certain areas of the globe. Coffee leaf disease, a true "rust," has so far not extended to the Southern American continent, though it has been known in Ceylon since 1868. The American gooseberry Mildew appeared for the first time in Western Europe within the last three or four years, though it has been known for a long time in the United States, and may be indigenous in Russia. In most cases the spread of these and similar diseases is probably to be traced to the direct agency of man. This belief is the basis of the numerous laws in various countries for preventing the introduction of certain diseases both of plants and animals. In India we are shut off from most of Asia by the vast barrier of the eternal snows to the north. We must then look to far distant countries, to Australia, to Persia and Egypt, for a possible source whence rust might reach India.

Experiment only can tell whether spores of the rust fungi can be found in the atmosphere in India before rust appears on the wheat. This has not yet been tried but has been arranged for and a full consideration of this possibility must hence be held over for the present.

If now we apply the above considerations to the problem as it presents itself in India, we can see where our knowledge of the life-history of the cause of the disease is deficient and to what points to direct our attention.

First: it is certain that the black rust caused by *Puccinia graminis* passes to the barberry and can be carried over on the latter plant until the new crop is ripe for infection. But this method, while accounting for only one of the several wheat rusts which occur (and that not at all the worst), does not account even for this except in a comparatively small number of cases, and certainly not so far as India and Australia are concerned.

Second: it is still possible, though unlikely, that the spores, whether uredospores or teleutospores, can retain their vitality until the following season and on germination infect the young wheat. But this is not supported by the results of experiments, and is besides opposed to the phenomena presented by the first attack of rust each year.

Third: it is possible, especially so in India where rusts have not been the subject of prolonged study, that other plants exist which may play a part in one or other of the Indian rusts, similar to that played in Europe and America by the barberry in black rust. But we have failed to find any such and the part played by intermediate hosts in cereal rusts must now be admitted to be practically negligible.

Fourth: it is, of course, possible that when all the rust-bearing plants of the plains have been investigated, they will still throw no light on the problem of the persistence of wheat rusts from season to season. This has been the case elsewhere. There then remains to be considered the theory of

Eriksson of the seed-borne germ, the experimental test of which is a matter of great difficulty. It requires work carried on over several seasons under conditions which approximate to those of the field, but which permit of the exclusion of foreign germs. The preliminaries of this have already been commenced at Cawnpore Farm.

III.—THE VARIETIES OF RUST IN INDIA.

In a previous note[1] it was shown that three different rusts commonly affect wheat and barley in this country, while a fourth has been found on a single occasion.

Of these, two of the commoner forms were identified as *Puccinia graminis* Pers. and *P. glumarum* Eriks. and Henn., while the third, owing to its having been found in only one stage of its complicated life-history—the Uredo stage—was not at that time capable of identification. In 1904 the Puccinia stage of the latter was produced abundantly and it has proved to be *P. triticina* Eriks.

There are, therefore, in India the two rusts which have attracted so much attention in the Australian colonies, *viz.*, *P. graminis* and *P. triticina*, while all three of the common Indian rusts are known in Europe.

The fourth rust, of which only a single specimen, on wheat, has been found, was obtained by Drs. Cunningham and Prain[2] at Saharanpur and spoken of provisionally by them as "Saharanpur rust." From its rarity it is probably of little economic importance. It will not be considered in the present note.

P. triticina differs from the other two common rusts in one particular of much interest. It seems in ordinary years to appear in one form only, the uredo-stage being abundant on the leaves while no other spore-form can be found. In 1896

[1] Butler, E. J., "The Indian Wheat Rust Problem." Bulletin No. 1, Department of Agriculture in India, 1903.

[2] Cunningham D. and Prain D. "A Note on Indian Wheat-Rusts." Records of the Botanical Survey of India, Vol. I, No. 7, 1896.

Drs. Cunningham and Prain were unable to find its teleutospores. In 1903 a large number of specimens was examined both in the laboratory and in the field by us with the same result; everywhere uredospores alone were produced. In 1904, however, teleutospores were formed freely, and this in several localities where no trace of them could be found the previous year. On the Cawnpore Farm, for instance, teleutospores were searched for unsuccessfully in 1903, at frequent intervals during a period of about two months, while the very same plots bore numerous teleutospores in 1904. At Dumraon in Bengal, and at Dehra Dun in the sub-Himalayan tract, the same fact was observed.

To give a more detailed account of the above rusts, so as to admit of their recognition with the naked eye, is far from easy; for they are extremely variable, and the appearance of a plant just showing the earliest attacks, and of one far advanced in a severe outbreak, may be totally different.

Puccinia graminis (plate I) is usually, so far as our experience goes, of late appearance. It is also, though the most formidable outwardly from the manner in which it scars and ruptures the attacked tissues, the least damaging to the grain. The evidence of Drs. Barclay, Cunningham and Prain, agree in this.

The uredospores are borne in elongated sori of a warm brown colour, which often become blackish later on from the development of teleutospores in the bed of the sorus amongst the uredospores. The sori are often a quarter of an inch or more in length, and we have found, where many run together, that a total length of several inches may be attained. The elongation is, as in most Uredineæ, in a direction parallel to the axis of the organ on which the fungus is situated. Coalescence laterally is common. The sori are found on the culms, leaf-sheaths and leaves; in severe cases on the glumes and awns as well. The relative degree to which each of these parts may be affected varies with the degree of severity of the attack, but in general it may be said that the culm and leaf-sheath are the

most favoured positions. The uredospores are elongated, oval or ovate, measuring 25 to 30 by 17 to 20 thousandths of a millimetre in diameter. The pores are arranged equatorially and are usually four in number, but sometimes more. This rust in Europe is variously stated to have two or four pores, while Cobb gives four as the number for Australia. Germination occurs readily in water, and we have obtained it freely several weeks after the spores were formed.

From the same mycelium, and often in exactly the same spot as the uredospores, the teleutospores appear at a later date. Their sori resemble those of the former in rupturing longitudinally, but they are black. The teleutospores are 40 to 60 by 15 to 20 thousandths of a millimetre in diameter.

The further history of this rust in India is unknown. As mentioned above, the teleutospore has not, as yet, been got to germinate here, and the barberry on which the æcidial stage appears does not occur on the plains. It is possible that there is no further history, that uredo-teleuto stage succeeds to uredo-teleuto stage without intermission season after season; or it is possible that another intermediate host than the barberry remains awaiting discovery, an event which would lead us to question the identification of this rust with *Puccinia graminis*.

On barley the rust is the same in its general characters.

Puccinia glumarum (plate II) is usually of earlier appearance than *Puccinia graminis*, and, as far as experience goes in India, is much more destructive to the grain.

The uredo-sori are of a pale yellow or lemon colour. They are formed chiefly on the upper surface of the leaves in mild cases, and on both surfaces of the leaves, on the leaf-sheaths, culms, glumes, and awns in severe. The under-surface of the leaf is never so closely covered with the sori as the upper. In a mild attack, such as that seen at Cawnpore in 1903, the first sign of the disease is the disappearance of the green colour of the leaf in longitudinal streaks. This occurs on the last formed leaf as well as on the radical leaves, and near the leaf

tip as well as near the base. It is followed very quickly by the development of the sori, as yellow pustules occupying the centre of the discoloured area, in one or more rows. Each row consists of a series of sori arranged end to end with the most perfect regularity, each being quite distinct from that above and below. The sori are small, shortly oval, and remain covered by the unbroken epidermis for a considerable time. Now this appearance is totally distinct from that which is found when a severe outbreak occurs. In the latter case the discoloured areas do not appear in streaks but cover large patches of the leaf, and the pustules come out in such quantities that the linear arrangement is lost or obscured, and the whole leaf appears to be covered with densely crowded yellow spots over both surfaces. Spores are shed from the sori in such numbers as to form a distinctly visible layer on the ground. They are spherical or shortly oval, and measure 23 to 35 by 19·5 to 35 thousandths of a millimetre in diameter. They have six or more pores, which, when six, are often arranged in two bands of three, midway between the equator and the poles.

The next stage is the development of teleuto-sori, which appear as black patches or spots, chiefly on the under-surface of the leaves, but also on all the other parts of the plant above ground. Sometimes these are arranged, especially on the sheaths and culms, in distinct linear series, but often they form more or less irregular patches of a horny consistence. The epidermis is not ruptured, and the appearance of flat black crusts is quite different from the raised gaping black wounds of the teleuto-sori of *Puccinia graminis*. The teleuto-spores measure 35 to 63 by 12 to 20 thousandths of a millimetre, the breadth being measured at the septum. The rust differs in one respect from the corresponding European one. In the latter the teleutospore beds are surrounded by "paraphyses," sterile club-shaped bodies developed from the fungus mycelium. In the Indian form our experience agrees with that of Dr. Barclay that these are not usually formed. This, no doubt, is a serious difficulty in identifying the latter

with *Puccinia glumarum*, but not, in our opinion, sufficient to separate them specifically.

P. triticina (plates III and IV) is, like *P. glumarum*, an early rust, possibly in most years the earliest of all to appear. What part it plays, as compared with the other two, in the total yearly damage of the crop is impossible yet to estimate. It has been found commonly in Bengal and the United Provinces and rarely or not at all in the Central Provinces, Central India, Bombay, Rajputana and the Punjab. It must be noted, however, that in the former provinces specimens were personally collected, whereas in the latter we have had to rely on a plant-collector and on specimens sent in by local officials who were not familiar with the different forms of rust. Drs. Cunningham and Prain collected what appears to have been this rust at Jeypore and at one or two localities in the Punjab in 1896.

The uredospores are borne in rounded or shortly oval sori of an orange colour, irregularly scattered over the upper surfaces of the leaves. They are never seated in rows on an elongated discoloured part of the leaf, as those of *P. glumarum* commonly are. Single ones may be found forming a minute point of brilliant orange on the leaf-surface, or groups near the base or apex or scattered irregularly over the leaf, accompanied when in large numbers by very considerable drying up of the leaf. On the under-surface, except in bad attacks, or on the leaf-sheath, pustules are rare, and we have only once seen one on the stalk itself. In this the difference to the other two rusts is striking. The uredospores measure about 23 to 32 by 21 to 28 thousandths of a millimetre in diameter, and are indistinguishable in shape, size, or the number of pores, from those of *P. glumarum*.

The teleuto-sori are found almost exclusively on the under surface of the leaf. They are brownish-black or dull black in colour, small, and remain long covered by the epidermis. Little difference can be noticed between them and those of *P. glumarum*, expect that an arrangement in rows is rare.

Each individual sorus is, however, broken up into several compartments, each surrounded by a sheath of closely set paraphyses or sterile erect bodies developed from the mycelium below the sori. These paraphyses serve to distinguish the sori from those of *P. glumarum* in which, contrary to what occurs in other countries, paraphyses are rarely found in India.[1] The teleutospores are very variable in form, rather like those of *P. glumarum*, with the apex often truncated or variously thickened. They measure 38 to 52 by 13 to 20 thousandths of millimetre.

Plates I to IV show the different appearances of the three common wheat rusts when seen in more or less typical examples. The following points of distinction can be noticed :

P. graminis attacks the stem most severely, then the leaf-sheaths, leaves and ears. The sori are large and elongated, run together, and early burst, often throwing up fragments of the epidermis around them. The uredosori are warm brown in colour, often becoming darker later on from the development of teleutospores in the same bed. The teleutosori are black, but otherwise resemble the uredosori. They never remain long covered over by the epidermis or form black crusts as in the case of the other two.

P. glumarum attacks the leaves most severely, then the leaf-sheaths, stalk and ears. The sori are oval, small, regular, not usually running together, and in mild attacks arranged in long rows on elongated discoloured parts of the leaf. They remain long covered by the epidermis. The uredosori are lemon-yellow and are formed on both surfaces of the leaf, while the teleutosori are dull black in colour and form small black crusts, chiefly on the under-surface of the leaves but also on the other affected parts.

P. triticina attacks the leaves almost exclusively, and the uredosori are found on the upper leaf-surface only, except in

[1] N. Speschneff notes in the "Zeitschrift für Pflanzenkrankheiten," Vol. IX, p. 357, that the form of *P. glumarum* found in the Caucasus is intermediate between those of Western Europe and of India as regards the number of its paraphyses.

rare cases. The sori are shortly oval, or round, variable in size but often larger than those of *P. glumarum*, while never reaching the size of well-developed sori of *P. graminis*. They do not often run together and are never arranged in regular rows like those of *P. glumarum*. The uredosori burst out early and are orange in colour. The teleutosori on the other hand remain long covered by the unruptured epidermis. They are dull black in colour and resemble those of the last species except in not forming long rows and in their minute structure as seen with the microscope. Where the two last species occur together on the one leaf, they are often hard to distinguish from one another.

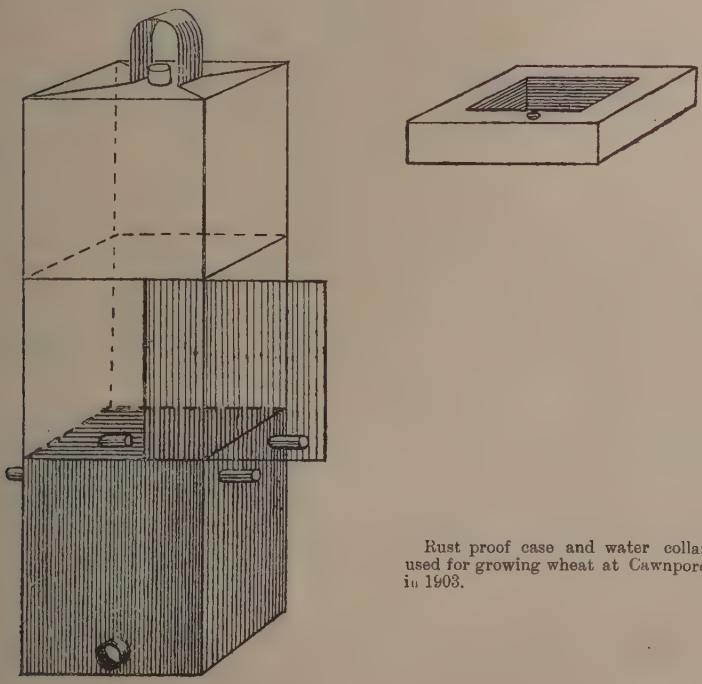
IV. EXPERIMENTS ON GROWING WHEAT IN RUST-PROOF CASES.

Some experiments were started by us at Cawnpore Government Experimental Farm, in 1903, to determine if rust would appear on wheat grown under conditions which exclude the possibility of external infection. If rust-liable wheats really contain within them, in some cases, the germ of the disease, rust must appear under these circumstances, if only the attempts are sufficiently numerous and carried out long enough. So far Eriksson alone has succeeded in this.

The first year's experiment was tentative and directed to test by actual trial the difficulties which might have to be surmounted in an attempt of this nature.

Four cases of the form shown in the accompanying cut were prepared. They were made of a tin box, 15 by 14 by 14 inches, to contain the earth. It was drained by an opening at the bottom of one side, to which was soldered a tube which was plugged by cotton wool. The orifice was closed by a wire gauze cap to prevent insects entering and carrying in infective material. Above the tin box the case was of glass fixed to tin supports to which the glass was morticed and fastened by putty. Ventilation was secured by four tubes plugged with cotton wool and provided with wire gauze caps

at opposite sides near the top of the earth-box, and a single larger opening at the top protected by a raised tin cap from rain. From this opening an incubator thermometer was suspended in the interior of the case. One of the glass sides was moveable in half its extent, being made to slide in grooves in the supports. This is shown shaded in the cut. Through this the box was filled at the beginning of the experiment with earth to which had been added cattle manure.



Rust proof case and water collar used for growing wheat at Cawnpore in 1903.

The interior of the case was sprayed with permanganate of potassium before filling. The earth was placed on a large iron pan and heated to 100° C. over a large fire. This temperature, though insufficient to destroy bacterial spores, is enough to ensure sterilisation as far as most fungi are concerned, and should be sufficient to exclude danger of uredospore infection from the soil. The earth was covered with a

large cloth dipped in corrosive sublimate after taking from the fire and filled into the cases as soon as it had cooled down.

A few air-borne spores gained entrance during filling and grew on the surface of the soil as moulds. Any danger from uredospores in the air was negligible, since three of the cases were filled on the 21st of January and the first rust of the year began on the Farm on January 25th, in a few small patches. The fourth it is true was not filled until the 30th, but they stood in a sheltered spot at a distance from the wheat fields and the risk of accidental infection was remote.

When each case was filled the sliding glass door was closed, and only opened again on the next day for sowing the seed.

The seed was sterilised by heating to 56° C. for 10 minutes. In each of three cases two seeds were sown and the door then sealed up with putty and not again opened. Of the 6 seeds only one germinated.

A second sowing was therefore made on January 31st. Seeds, heated as before to destroy adhering spores, were first germinated in sterilised Petri dishes and two were sown in each case by means of a long bent spoon-shaped piece of tin inserted through one of the side tubes. These all grew, giving 9 plants in all. The experiment was therefore on a very small scale, as it was merely intended to ascertain the conditions requiring attention.

Four points have to be especially considered in growing plants under unnatural conditions such as these. They are temperature, light, air and water.

The temperature in the cases was taken at frequent intervals and compared with that of the outside air. The following table gives some of the figures obtained. It must be noted that at the beginning of the experiment, the cases stood in shade in an open verandah, but on the 1st of February they were moved out into the sun, and the glass coated with a thin layer of whitewash.

Date.	Hour.	Temperature (Fahr.) within case.	Temperature (Fahr.) outside.	Difference.	Remarks.
January 23rd	2 P.M.	70	69	+1	Cases in open verandah.
,, 24th	7-30 A.M.	56	56	0	
,, ,,	2 P.M.	74	71	+3	
,, 27th	7-30 A.M.	52	53	−1	Temperature not recorded on 25th & 26th.
,, ,,	2 P.M.	68	67	+1	
,, 28th	7-30 A.M.	46·5	46·5	0	
,, 29th	7-30 A.M.	47	47	0	
,, ,,	2 P.M.	66	66	0	
,, 30th	7-30 A.M.	52	52	0	
,, ,,	2 P.M.	68	67	+1	
,, 31st	7-30 A.M.	50	50	0	Cases moved out into the open and whitewashed on February 1st.
,, ,,	2 P.M.	70	70	0	
February 2nd	12 noon	94	95	−1	Temperature not recorded on February 1st.
,, 3rd	12 noon	95	95	0	
,, 4th	7-30 A.M.	46	47	−1	
,, 5th	7-30 A.M.	39	39	0	
,, ,,	1 P.M.	96	102	−6	
,, 6th	1 P.M.	99	98	+1	
,, 7th	7-30 A.M.	41	43	−2	
,, ,,	1 P.M.	100	98	+2	
,, 8th	7-30 A.M.	40	45	−5	
,, ,,	1 P.M.	96	93	+3	
,, 9th	7-30 A.M.	42	45	−3	
,, ,,	1 P.M.	90	96	−6	
,, 10th	7-30 A.M.	46	46	0	
,, 17th	2 P.M.	89	96	−7	Temperature not recorded from 11th to 16th.
,, 18th	8 A.M.	63	63	0	
,, 19th	7-30 A.M.	52	52	0	
,, ,,	1 P.M.	100	96	+4	
,, 20th	7-30 A.M.	52	52	0	
,, 22nd	7-30 A.M.	50	50	0	Temperature not recorded on 21st.
,, ,,	1 P.M.	84	83	+1	
,, 23rd	7-30 A.M.	50	51	−1	
,, 24th	7-30 A.M.	49	50	−1	
,, ,,	1 P.M.	103	100	+3	
,, 25th	9 A.M.	60	61	−1	
,, 26th	8 A.M.	60	62	−2	
,, 27th	7-30 A.M.	58	59	−1	
,, ,,	10-30 A.M.	103	102	+1	

These figures show that in twelve observations made while the cases stood in shade on a verandah, the average variation from the outside temperature was about ·6°, while in 27 observations taken after the cases were moved out into the open, the variation was under 2°. Of the latter, in fifteen

observations made in the morning when the temperature within and without might be expected to be more nearly equal after the night, the average variation was a little over 1°; while of 12 observations made during the heat of the day, the average variation was nearly 3°. The greatest variations noted in 39 observations were one of 7° and one of 6°. It is hard to believe that a variation so slight as these figures show, could so modify the conditions of growth, either of the host or its parasite, as to render the results not comparable with those to be got in the field.

As regards light, the cases stood for the first nine days out of reach of the direct rays of the sun. They were then moved into the open and the glass whitewashed.

Air was admitted by the openings already described. Four were at the level of the surface of the soil, and one at the top of the case. One of the former was later on closed by the watering apparatus described in the next paragraph.

Watering, in experiments of this kind, is one of the chief difficulties. Evaporation is naturally checked by the presence of the case, and the earth has a tendency to become sodden if heavy waterings are given. A means was at first devised of obtaining a steady supply of water in small quantities. A hollow earthenware collar of the form shown in the cut on p. 31 was prepared large enough to just fit within the box. One opening was provided on the upper surface (which was flush with the surface of the earth) and arranged so as to lie directly under one of the side air-holes. From this latter an extension of the external tubing into the interior permitted of a stream of water being directed so as to fall into the hollow collar. The water was provided from a small boiler placed over a small brick fireplace close to the cases, so that the water could be boiled on the spot. From each boiler a T-tube fed two adjacent cases. Thus each pair of cases had an entirely distinct water-supply. The boiled water was admitted by opening a pinch-cock into the earthenware collars, and thence percolated slowly and continuously into the earth. It was

found that the collar should be filled every ten or twelve days in order to keep the earth uniformly moist.

Under these conditions the wheat grew fairly and flowered, one plant stooling out into 32 heads. As it was sown so late, however—eleven weeks after the wheat on the farm—the temperature towards the end was too high to grow wheat in a satisfactory manner, and the plants suffered much in growth and did not properly mature the grain. No rust appeared on any of the plants, which were removed for examination late in April. Rust was common but not particularly severe on the farm.

In 1904, circumstances again prevented the wheat being sown in time. Six cases were used this year, but instead of filling the lower case directly with earth the latter was placed in a separate inner box. These boxes which were 13 by 9 by 9 inches were filled with earth, the top being covered by a cloth, and were sterilised in a Koch's steriliser by steam at 100°. They were then placed in the cases through their sliding doors and the cloth removed. The interiors of the cases themselves were sterilised by burning sulphur, which it was found could be done both before putting in the earth-boxes and afterwards, through one of the air tubes, to destroy any spores which might gain access through the exposure necessary while introducing the boxes. This sterilisation was not, however, any more effective than in the previous year, for moulds appeared as before in some of the cases. The latter were kept in the open from the beginning. The seed was prepared and germinated as before, and germinated seeds were sown in the six cases on January 5th and the following days. The air holes this year were made larger. Watering was arranged for as before, except for the omission of the earthenware water boxes, whose advantage, it was found, scarcely compensated for the difficulties of sterilisation. About thirty plants were grown in all and no rust had appeared when the cases were opened in April.

In 1905, 36 plants were grown in a similar manner and no rust appeared.

In 1906, 40 plants have been grown without any sign of rust up to date (March 9th).

The number of the experiments, so far, is much too small to admit of any conclusions being drawn. It is not to be anticipated that the internal germ, if one exist, occurs in any large proportion of grains. Even in a rust-liable wheat, such as was used for the experiment (one known as *Kathia* which has shown on the farm that it is little resistant to the disease) it is extremely probable from the nature of the first onset of the disease that only a few grains would be infected. The great proportion of pustules arises from secondary *Uredo* infection and the assistance of an internal germ need only be invoked to explain the primary attack, which is usually slight.[1] Afterwards extension depends very largely on the conditions which favour the dissemination of the first-formed spores, and their germination on new plants. The experiments will be continued in the future but several years must elapse before any conclusions can be drawn. So far no positive results have been obtained which favour the assumption of the existence of Eriksson's Mycoplasm.

V. DISTRIBUTION OF CEREAL RUSTS IN INDIA.

The following table shows the distribution of the different varieties of rust in a considerable area of Northern and Central India in 1904. Rust was not prevalent in this year in India, and the wheat crop was a record one. It is possible, or even probable, that the table possesses a relative value only, and that the distribution varies to some extent from year to year. In years of severe rust it appears likely, from the observations of Drs. Cunningham and Prain in 1896, that *P. triticina* takes a large extension. Further observations are particularly necessary in Central India where *P. graminis* was found to be far the commonest rust in 1904. As this part of the country suffers most severely from rust in bad years, and

[1] See Butler, E. J. "The bearing of Mendelism on the susceptibility of Wheat to Rust," *Journal of Agricultural Science*, Vol. I., Pt. III, 1905, for a somewhat fuller discussion of this point.

as our observations in the United Provinces and Bengal go to show that *P. graminis* is not ordinarily capable of causing as much injury as the other two, it becomes of much interest to determine what rust is prevalent in Central India in years of bad disease. In the bad rust year, 1901, the Australian wheats on the Cawnpore Farm suffered more severely from the attacks of *P. graminis* than the local varieties.

DISTRIBUTION OF THE DIFFERENT RUSTS IN 1904.

Locality.	No. of rusted fields visited.	P. graminis.				P. glumarum.				P. triticina.				Remarks.
		I.	II.	III.	IV.	I.	II.	III.	IV.	I.	II.	III.	IV.	
Sangor ...	1	1	...	...	...	...	...	...	...	.	...	...	...	.....
Damoh ...	5	2	...	1	...	..	...		2	...	..	...	...	.....
Jubbulpore ..	28	6	7	9	4	4	...	2	...	...	...	...	...	Some of the specimens had both P. graminis and P. glumarum.
Nagpur ...	...	19	1	1	...	...	...	..	...	...	...	...	..	Twenty-one specimens of rusted wheat collected at the Government Farm, chiefly different varieties of wheat.
Badnera ...	25	2	13	8	2	...	...	...	...	...	...	...	...	.....
Khandwa ...	16	16	...	...	...	...	...	...	...	...	...	...	...	.....
Hoshangabad	24	1	3	13	7	...	...	..	.	...	...	...	...	.....
Neemuch ...	22	4	4	5	8	1	...	2	1	..	...	...	...	In addition one specimen of Barley with P. graminis in the degree I was collected.
Ajmere ...	17	4	3	...	1	3	4	1	3	...	...	...	...	.....
Jaipur ...	11	...	2	2	4	1	3	...	...	...	...	...	...	In addition four specimens of Barley with P. glumarum, two in the degree II and two in the degree III were collected.
Alwar ...	16	4	1	3	...	2	7	4	2	...	...	...	...	In addition two specimens of Barley with P. glumarum in the degree III were collected.
Saharanpur ...	16	1	...	...	...	5	2	1	7	10	...	2	...	.....
Lakhsar ...	5	...	...	...	...	2	2	...	...	2	...	3	...	.....
Dehra Dun ...	...	...	...	...	...	...	...	...	...	...	...	...	...	A number of fields examined containing all three rusts in varying degrees.
Cawnpore ...	...	..	...	1	...	...	1	..	...	...	1	...	...	Several varieties of wheat variously affected with the three rusts on the Government Farm.

DISTRIBUTION OF THE DIFFERENT RUSTS IN 1904—(*contd.*)

Locality.	No. of rusted fields visited.	P. graminis.				P. glumarum.				P. triticina.				Remarks.
		I.	II.	III.	IV.	I.	II.	III.	IV.	I.	II.	III.	IV.	
Dumraon ...	...	...	1	...	...	1	...	...	...	...	...	...	1	Several varieties of wheat sent from the Experimental Farm with all three rusts.
Gaya ...	...	...	...	...	..	...	...	...	..	...	...	1	...	A specimen sent by the District Officer.
Gopalgunj ...	...	...	...	...	...	...	...	...	...	...	...	1	..	Ditto.
Sasaram ...	...	...	...	...	...	...	1	...	...	...	...	1	...	Ditto.
Shahabad ...	...	..	...	...	...	...	1	...	...	...	...	...	...	Ditto.
Pusa ...	...	...	...	...	...	...	...	...	1	1	...	...	...	Specimens collected on the Pusa Farm.
Poona ...	...	...	1	...	...	...	1	...	...	...	...	...	...	Seven varieties of wheat sent from the Government Farm, Kirkee, all affected with both rusts.

The figures I, II, III and IV under each variety of rust indicate the degree of attack, I being the mildest.

In the Punjab and Sind there was little rust in 1904, and we obtained no specimens from these provinces. From South India also no information was available, but we have seen specimens of rusted wheat in the Herbarium of the Government Botanist, Madras, showing that in the Pulney Hills *P. graminis* and *P. glumarum* occur.

It may be considered as now established that wheat rust occurs in every wheat-growing province of India. In the Punjab it is comparatively mild, owing no doubt to the dry climate, but with the extension of irrigation it shows a distinct tendency to increase in severity. In the southern parts of India wheat is not extensively grown, and rust is probably not a large item in the yearly tax levied by fungi on the cultivators. But in the whole of the country enclosed in the triangle formed by lines joining Bombay, Simla and Calcutta, rust is endemic, extremely destructive, and usually more than one of the three varieties is concerned.

VI. SPECIALISATION OF THE FORMS OF RUST ON DIFFERENT HOST-PLANTS.

The majority of the *Uredineæ* or Rust-fungi, in the uredo-teleuto stage, attack a single species of the flowering plants only. Some, however, are able to live on several species. In the latter case the species are usually allies, and only a few instances occur where the fungus is able to attack two species far removed from each other in the vegetable kingdom.

The uredo-teleuto stages of the three rusts referred to in this paper are all capable of attacking more than one species. Thus *P. graminis* has been found, in various countries, on about 50 different grasses, including wheat, barley, oats and rye; *P. glumarum* on about 6 grasses, including wheat, barley and rye, and *P. triticina* on wheat and rye only.

Of late years it has become more and more established that parasitic fungi, which are capable like these rusts of living on several hosts, tend to develop "races" on their different host-species, marked off from each other by definite characters. Sometimes the characters are such as are capable of being detected microscopically. Usually, however, the fungi are, to all appearance, identical, and differences only appear when their manner of life is carefully studied. The chief of these is the incapacity of a race to attack the host-plants of another race. Such forms as are thus outwardly identical but which show a constant difference in their mode of life are known as "biological" species or as *formæ speciales*.

A specialised form is considered to be "sharply fixed" or "not sharply fixed" according as it is wholly incapable, or sometimes capable, of attacking the host-plants of the other specialised forms of the same fungus. Thus the *P. graminis* of wheat (*P. graminis f. sp. Tritici*) is not sharply fixed, for it can attack barley, rye, &c., sometimes. The *P. graminis* found on grasses of the genus *Agrostis* (*P. graminis f. sp. Agrostis*) is sharply fixed, for it attacks this genus only and does not pass to the other grasses on which it has been tried.

But even the not sharply fixed forms, such as the *P. graminis* of wheat, may be entirely incapable of attacking some of the species which bear other forms of the same fungus. In other words a form may be not sharply fixed in regard to some host-plants and sharply fixed in regard to others. A striking instance of this occurs in India. *P. graminis* can be divided amongst others into races on wheat (*f. sp. Tritici*), rye and barley (*f. sp. Secalis*), and oats (*f. sp. Avenæ*). The *f. sp. Tritici* can attack barley sometimes, and as the table below shows did so in four out of sixteen of our inoculations, but it does not, in India at least, attack oats. Hence it is sharply fixed in regard to oats and not sharply fixed in regard to barley. The *f. sp. Secalis* on barley also does not pass to oats, but infected wheat doubtfully in two out of sixteen inoculations tabulated below. These two forms are common in India, and the practical bearing of their not passing to oats is considerable, for the *f. sp. Avenæ* has not yet been observed in this country. Hence oats, which are particularly liable to rust in other countries, and commonly to *P. graminis*, can in India be grown in perfect health side by side with severely rusted wheat and barley. This was very marked at Hissar Farm, in 1903, where much of the wheat was damaged by black rust, while not a trace could be found in the large area surrounding under oats. Indeed, no sort of rust has yet been reported on oats in India,[1] and in Dehra Dun where oats are largely grown, the contrast between the rusted wheat fields and the non-rusted oats is remarkable.

It is probable, from Barclay's observations already mentioned, that the *P. graminis* found at Simla on a jungle grass is a specialised form which does not ordinarily pass to cereals.

The following table gives some inoculations made in 1903 and 1904 with the three common rusts in order to test the degree of their specialisation.

[1] A very puzzling fact, telling strongly against the atmospheric communication of rust from afar, and also against the Mycoplasmic Theory.

Date.	Spores from	Inoculated on	No. of plants inoculated.	No. of plants infected.	Remarks.
		PUCCINIA GRAMINIS.			
March 31st, 1904.	Hordeum vulgare.	Triticum vulgare...	16	2	Two doubtful spots only.
April 1st, 1904...	Hordeum vulgare.	Hordeum vulgare	4	3	Spores germinating only fairly well.
April 1st, 1904...	Triticum vulgare.	Hordeum vulgare	19	4	Five plants showed no trace of infection and one was doubtful.
April 19th, 1904	Triticum vulgare.	Hordeum vulgare.	4	0	
April 19th, 1904	Triticum vulgare.	Hordeum vulgare.	2	0	
		PUCCINIA GLUMARUM.			
Feb. 27th, 1903.	Hordeum vulgare.	Triticum vulgare	1	0	
Feb. 27th, 1903.	Hordeum vulgare.	Hordeum vulgare	1	1	
March 9th, 1903.	Hordeum vulgare.	Triticum vulgare	1	0	
March 9th, 1903.	Hordeum vulgare.	Hordeum vulgare	1	1	
March 24th, 1904.	Hordeum vulgare.	Triticum vulgare ...	14	0	
April 9th, 1904.	Hordeum vulgare.	Avena sativa ...	19	0	
April 9th, 1904.	Hordeum vulgare.	Phalaris minor ...	...	0	Number of plants inoculated lost but about ten.
April 9th, 1904.	Hordeum vulgare.	Triticum vulgare...	38	0	
April 9th, 1904.	Hordeum vulgare.	Triticum vulgare...	8	0	
Feb. 19th, 1904.	Triticum vulgare ..	Hordeum vulgare.	7	0	
March 8th, 1904.	Triticum vulgare...	Hordeum vulgare.	15	5	Pustules fairly numerous on the infected portions of five plants.
March 8th, 1904.	Triticum vulgare...	Triticum vulgare ...	12	12	
March 8th, 1904.	Triticum vulgare...	Phalaris minor ...	23	1	Numerous pustules on the infected portion near the tip of one leaf.
March 29th, 1904.	Triticum vulgare...	Hordeum vulgare.	8	0	
Mar. 31st, 1904.	Triticum vulgare...	Phalaris minor ...	12	0	
April 8th, 1904.	Triticum vulgare ..	Avena sativa ...	80	0	
		PUCCINIA TRITICINA.			
Mar. 11th, 1903.	Triticum vulgare.	Hordeum vulgare.	1	0	
Mar. 11th, 1903.	Triticum vulgare.	Triticum vulgare.	2	2	
Mar. 12th, 1903.	Triticum vulgare.	Hordeum vulgare.	1	0	
Mar. 12th, 1903.	Triticum vulgare.	Triticum vulgare.	1	1	Plants dried up early from over-exposure.
April 13th, 1904.	Triticum vulgare.	Triticum vulgare.	1	1	
April 19th, 1904.	Triticum vulgare.	Hordeum vulgare.	4	0	
April 30th, 1904.	Triticum vulgare	Triticum vulgare.	1	1	
May 14th, 1904.	Triticum vulgare.	Hordeum vulgare.	20	0	

From this table it appears that the *P. graminis* of wheat (*f. sp. Tritici*) is not sharply fixed in regard to barley, four inoculations having succeeded. This is in agreement with the results obtained both in Europe and in the United States. The fixation of *P. graminis f. sp. Secalis* is doubtful. *P.*

glumarum f. sp. Tritici is not sharply fixed in regard to barley five out of thirty inoculations having succeeded. The experience in Europe seems to indicate that there the rust does not pass to barley. Hence the yellow rust seems to have a different specialisation in the two regions, and a similar fact has been noted in regard to the North American and European black rusts. *P. glumarum* from wheat was once successfully inoculated on *Phalaris minor* and failed thirty-four times. It failed to infect oats. *P. triticina* was unsuccessfully tried on barley. It may be mentioned that the inoculations were made partly on plants grown in pots, and partly on plants totally immersed in glass cylinders grown under sterile conditions, the openings being plugged with cotton-wool, the whole sterilised and sterile seeds used. All inoculations made with *P. graminis* were under the latter conditions.

VII. RESISTANCE TO RUST OF DIFFERENT VARIETIES OF WHEAT.

Our information on this head is still lamentably deficient. It is certain that varieties show a marked difference in their behaviour to rust, and it is in the study of these differences that the chief hope at present lies of appreciably diminishing the disease. In Australia this line of work has been pushed very far, and a full account of the progress in that country has been given by Dr. Prain.[1] Unfortunately it appears that the power of resistance is not maintained when wheats are moved from one climate to another. Several Australian wheats believed to be resistant have failed when tried in India. On the other hand, "Kathia," which is very liable to all three rusts at Cawnpore, was found by Carleton to be worth recommending for trial as a resistant sort to *P. triticina* in the United States.[2] Even within the boundaries of India it is probable that resistance in one locality will not mean resistance in another. Thus spelt wheat, which in Bombay and at Hissa-

[1] "Rust in Wheat in the Australian Colonies," Agricultural Ledger, 1897, No. 16.

[2] It is not certain that Carleton's "kathia" was the same strain as the Cawnpore "kathia."

is highly resistant, was stated to have rusted badly at Nagpur in 1903 (Report on the Nagpur Experimental Farm for 1902-3). And again it is known that resistance to one rust does not imply resistance to the others. Hence there is a large amount of work to be done before a comprehensive account can be given of the sorts of wheat which show qualities sufficient to warrant efforts being made to extend their cultivation.

Each of the larger climatic divisions of the wheat-growing districts must work out its resistant varieties for itself. The labour of getting true varieties together for experiment is alone considerable. Then these must be grown together under similar conditions for some years and careful record kept of the varieties of rust by which they are attacked and the degree of attack. Until a clear knowledge has been obtained of the rusts which attack wheat no reliable distinction between them can be looked for. It is hoped that the illustrations and description of the three important rusts here given may enable them to be separated, and it will thus be possible to determine the comparative resistance to each of the different sorts of rust in each locality. Results must be expected to come slowly, and nothing could be more fatal to ultimate success than undue haste. Several of the Provinces are now interested in the question, and the development of this method of dealing with rust in India—the only one at present giving great promise—lies in the near future.

VIII. METEOROLOGICAL CONSIDERATIONS.

In 1892, Dr. Barclay[1] endeavoured to trace a connection between the variations in the price of wheat from year to year in India, and the occurrence of climatic conditions which might favour the attacks of rust. He considered that a decided though not perhaps a close parallelism might be expected between the weather conditions in the months of January, February and March in so far as they favoured or retarded the growth of the parasite, and the prices of wheat. This

[1] "Rust and Mildew in India," Journal of Botany, Vol. 30, 1892.

parallelism his figures showed actually existed. On the whole, whenever the cloud humidity and rain were considerable in these months, the prices rose.

The data were wanting in one particular. No actual records existed of the degree of rustiness of the years selected for analysis. The assumption had therefore to be made that if in any year the weather conditions were generally favourable to the growth of the wheat plant, and yet the price remained high, the influence of the parasite must be taken to explain the high prices. This assumption, though no doubt often correct, is not entirely satisfactory. It does not, for instance, allow for the area under wheat in any given year—a variable factor—nor the time of sowing (depending from year to year on the late monsoon rains), nor the climatic conditions influencing the germination of the seed, since his observations did not include the months of October and November.

Yet all these influence prices to some extent. Allowing, however, for this, the figures disclosed an interesting connection between the amount of rain, cloud and humidity in the months of January, February and March, and the indications of rust prevalence as shown by the price of wheat.

Knowing the fondness of the Indian cultivator to attribute the diseases which affect his crops to a deficient, rather than to an excessive, rainfall, we thought it would be interesting to find out his views with regard to rust and to see if they agreed or differed from Barclay's conclusions.

The Punjab, where rust is quite well known to the cultivators under the names of *kungi*, *roli*, etc., was selected for enquiry, and Mr. Renouf, I.C.S., Director of the Department of Land Records and Agriculture, kindly ascertained for us, through the local officials, the opinions held in a number of districts. As will be seen below there is remarkable unanimity in attributing the prevalence of rust in any year to cloudy weather, especially following rainfall or excessive irrigation. So far the enquiry indicates that rust actually does

become prevalent when the climatic conditions favour it in the way suggested by Barclay.

Locality.	Rust considered due to.
Jhelum	Rainfall followed by cloudy weather or heavy dew after rain, chiefly in damp soils. Good rain followed by sunshine causes it to disappear.
Rohtak	Over-abundance of rain with cloudy weather.
Umballa	Plentiful rain with cloud in 1901. When heavy rain with intervals of sunshine came, the crop recovered.
Hissar	Heavy rainfall or excessive irrigation, followed by damp and want of sunshine for several days.
Mianwali	Over-saturation of the soil by rain or floods, with prolonged cloud.
Montgomery ...	Deficiency of rainfall and irrigation water in inferior lands. Continuance of cloudy weather without wind, sunshine or rain. Clear nights, with cloudy days and no rain or sunshine, especially from December 15th to February 15th. Rains, sunshine and strong winds are the best remedy.
Ferozepur	Rainless cloudy weather. Some say close sunny days also produce it. More common in riverside villages.
Lahore	Opinion unanimous that "kungi" appears at the time when clouds have been hanging for several days and it has not blown.
Delhi	Moisture in the fields. Excessive winter rain and cloudy atmosphere for a lengthened period, with east winds. In bright sunshine with west winds the disease loses its force.
Chenab Canal ...	Prevalence of cloudy weather in January or February. Bright sunshine after rain is the only remedy known.
Rawal Pindi ...	Attributed to excessive rainfall followed by cloudy weather.
Mooltan	Cloudy weather and little or no rain in January and February.
Jullundar	Heavy rain followed by cloudy weather.
Hoshiarpur ...	Excessive moisture followed by cloud. Higher lands in the hills are rust-proof.
Karnal	Heavy rain succeeded by cloudy weather for two or three days.
Jhang	Cloudy weather for days without good rainfall.
Sialkot	Deficiency of rainfall and irrigation water. Said to be due to cloudy weather after heavy rain.
Gurdaspur	Fog, dew or excessive rain followed by feeble sunshine. Good rain followed by good sunshine makes it disappear.
Gujrat	Abundant rainfall followed by cloudy weather without sunshine.
Muzaffargarh ...	Excessive rainfall.
Shahpur	Cloudy weather for days.
Ludhiana	Extra moisture in the soil and cloudy weather for several days at a time.
Gurgaon	Cloudy weather; also excessive rainfall accompanied by high easterly winds and clouds.
Kangra	Excessive rain followed by cloudy days.
Amritsar	Crops standing in water during continued cloudy weather. Also deficiency of rainfall on "barani" lands.
Gujranwala ...	Excessive winter rain followed by cloudy weather. Occasionally produced by drought and deficiency of canal water.

The views given above are sufficient to show that in the Punjab the opinion is generally held that rust is induced by moist, cloudy weather. They make no reference to the belief sometimes held that excessive moisture in the soil at the time of sowing brings on rust. The moisture at the actual period of rust susceptibility appears to be the determining factor and not at any previous period during the growth of the crop. In Europe on the other hand Eriksson holds that for *P. glumarum*

moisture in April in Sweden conduces to the rust which often does not appear until June or July. That no support is given to this by the observation in India is perhaps to be expected from the much shorter wheat season here than in Europe. In Mr. Moreland's note, which follows, the conditions for three districts of the East and South of the United Provinces are analysed, and it is clearly shown that moisture in January and February (the months when rust first appears in these localities) is the deciding element.

IX. THE MEANS OF COMBATING RUST.

In the absence of exact knowledge of the origin of the disease, remedial measures could not be expected to have obtained a considerable degree of success. As a matter of fact they are confined practically, at the present moment, to providing sorts of wheat little liable to the disease. This method has been remarkably successful in Australia, but its adoption is attended with a good deal of difficulty. It is not always easy to persuade the farmer to grow a variety on the chance that it will be a bad rust year, and that the variety is likely to suffer less than the others. At the same time it is the only method to be recommended at the present day, and it is certainly capable of great developments and of saving an enormous sum of money annually lost from the disease. As our knowledge increases, it is not unlikely that some of the simpler methods now discredited, such as seed treatment, or manuring, may be modified so as to become effectual in checking the disease. But it is evident that nothing much can be done as long as the all-important question, from a practical point of view, of the origin of the disease, remains unanswered, at least in a manner to force acceptance.

Professor Eriksson, to whom, whether his final theory will stand the test of time or not, we still owe more of our knowledge than to any other single worker, gives as a result of his

long experience the following suggestions for the organization of future investigations :—

"1. In every country where the rust of cereals is of great practical importance a special experiment station should be established to conduct investigations on the rust of cereals. At this station field experiments with the varieties of cereals cultivated in the country should be organized to test their resistance to the different forms of rust appearing in the country.

"2. According as information is acquired, by trials carried on continuously for at least five years, regarding the qualities of the different varieties of cereals and the different forms of rust found in the country, it will be possible—

(*a*) to cease to cultivate the varieties which by these trials have been shown to be very liable to one or other of the more dangerous forms of rust, and to choose amongst the other varieties those which have displayed a sufficient resistance to cold, which have ripened early, which have yielded freely, and which have united these qualities to others of value;

(*b*) to determine by research, formulated and carried out on a systematic plan, in what degree the external conditions of soil, situation, manure, season, etc., are capable of influencing the rusting of the future crop—for these trials varieties which have been found very liable to one or other form of rust should be chosen; and

(*c*) to endeavour by rational cultivation, by improvements and by crossing certain sorts which have shown valuable qualities, to obtain races which from every point of view can be considered as the most advantageous for the country.

"3. Finally—the question of the rust of cereals being of the greatest practical importance for every country—means should be furnished to those in whose hands the direction of

these investigations are placed, to meet from time to time, that is to say, at least every five years, in order to discuss, according as experience is gained, the value of any new observations and to gain for their work the advantage of being based on a plan common in its essentials to all.''

SUMMARY.

Three distinct rusts, *Puccinia graminis* (black rust), *Puccinia glumarum* (yellow rust) and *Puccinia triticina* (orange rust) commonly attack wheat (all three) and barley (the first two), in India. They may be distinguished by their colour and still more by the parts of the plant ordinarily most severely affected. Microscopically the differences are more evident.

No entirely satisfactory explanation has yet been given of the way in which the disease originates each year. There is strong reason to believe that it cannot arise from spores from the previous crop, nor to any great extent from other grasses affected with the same rusts. No "intermediate'' host (bearing the fungus in the æcidial stage) has been found, nor is likely to be found, which can commonly produce the disease in the greater part of the infected area. A hereditary origin is possible through the use of infected seed, but is not proved as far as India is concerned. The possibility of infection by spores deposited from the atmosphere having their origin in other wheat-growing countries is under investigation.

A small number of wheat plants was grown in germ-tight cases in 1903 and subsequent years, and escaped rust. The number is as yet too small to base conclusions on, and further experiments are in progress.

Rust has been found on wheat, and the fungus concerned identified, over a large area of the wheat districts. *Puccinia triticina* has been found most commonly in the Eastern districts, *P. graminis* in the Southern and *P. glumarum* in the Northern. These results are not of general application, as the number of observations is too small as yet. There is, however,

no room for doubt that in 1904, *P. graminis* was the predominant rust in Central India, and much less general under the hills, where *P. glumarum* and *P. triticina* were found most frequently. The interest of this lies in the fact that the only intermediate hosts for any of the rusts known in India are the barberries near Simla which bear the æcidia of *P. graminis*, which hence might have been expected more generally on the wheat of the North if it had arisen from its intermediate host.

Each variety of rust usually attacks several plants, *P. graminis* having been found on about 50 grasses in different countries. However, there is a tendency to develop races for each host plant which do not easily attack the other host plants. In India oats are not attacked by the black rust of wheat or barley, and as their own particular race of parasite does not appear to have been yet imported, they entirely escape the disease. The black rusts of barley and wheat are capable of cross infection with a certain amount of difficulty. Yellow rust of wheat can also sometimes pass to barley. Orange rust is confined to wheat.

It is now possible, with the information at our disposal, to endeavour to produce resistant varieties of wheat on a rational plan. The resistance to each kind of rust must be considered separately, for resistance to one does not imply resistance to the others. So also each considerable climatic division of the wheat-growing parts of the country must work independently, for the resistance of a variety is possibly affected by change of locality.

Moisture, as indicated by cloud, and to a lesser extent an excess of water in the soil induce rusting of the crop.

Help can be given by those whose interest may be aroused in several directions in which further information is much needed.

Rusted grasses and other plants occurring in the wheat districts are wanted in order to get as complete a list as possible of other plants attacked by the cereal rust fungi. They may be sent to Pusa.

The variety of rust found most commonly year by year in the different parts of the country can be determined, or, when in doubt, specimens may be sent to Pusa or to Cawnpore Experimental Farm. In a bad rust year information is particularly needed which rust in each province does the greatest damage or if all increase in intensity.

Search for resistant varieties may result in the discovery of good sorts which have escaped notice up to the present. These can then be tested carefully on some of the Government Farms and their resistance perhaps developed by selection or crossing.

Finally, further accurate meteorological observations in their bearing on the appearance of rust are wanted, particularly in the eastern and central parts of the country.

DESCRIPTION OF PLATES.

PLATE I.—*Puccinia graminis*, Pers on wheat. Fig. 1, leaf-sheath and portion of leaf showing uredo and teleuto-sori. Fig. 2, portion of a leaf with confluent uredo-sori. Fig. 3, portion of a stalk ruptured by crowded uredo and teleuto-sori. Fig. 4, portion of a leaf with teleuto-sori. Figs. 1—2, natural size; Figs. 3—4, magnified.

PLATE II.—*Puccinia glumarum*, Eriks. and Henn. on wheat. Figs. 1 and 2, leaves with a portion of the sheath and stalk showing different degrees of attack. Figs. 3 and 4, portions of stalks with uredo and teleuto-sori. Fig. 5, portion of a leaf with uredo and teleuto-sori. Figs. 1—4, natural size; fig. 5, magnified.

PLATE III.—*Puccinia triticina*, Eriks. on wheat. Leaves showing different degrees of attack. Natural size.

PLATE IV.—*Puccinia triticina*, Eriks. on wheat. Fig. 1, leaf with a portion of sheath and stalk showing fungus confined to the leaf blade. Fig. 2, severe uredo attack on a leaf. Fig. 3, uredo-sori on upper surface of a leaf. Figs. 4 to 6, teleuto-sori on under surface of leaf. Figs. 1, 2 and 6, natural size; Fig. 5, ×8; Figs. 3 and 4, ×16.

PLATE V, FIGS. 1 AND 2.—*Æcidium montanum* Butl. on *Berberis Lycium* from the Mussoorie Himalaya. Fig. 1 "witch's broom" type, showing several branches with small leaves growing sharply upwards ("negative geotropism"), and having on the base of these, and on some small deformed leaves, æcidial cups. Fig. 2, non-deforming type, on normal leaves, showing the long æcidial cups. Fig. 3, *Puccinia graminis*, æcidial stage on *Berberis Lycium* from the Simla Himalaya. Fig. 4, *Chytridiacean* parasite of *Pythium vexans*, showing the entry of the naked zoospore protoplasm into the filament. *a*, *b* & *c* drawn at intervals of five minutes. In *c* the small mass of parasitic protoplasm of the zoospores *z*, which had just penetrated, may be seen in the midst of the protoplasm of the host. Fig. 1 reduced; Figs. 2 and 3, natural size and Fig. 4 × 450.

(Plates I to IV were drawn by M. A. Descubes, C.E., except Fig. 5, plate II, Fig. 1, plate III, and Figs. 2, 5 and 6, plate IV, which, with Figs. 1, 2 and 3, of plate V were drawn by H. Hormusji Deboo; Fig. 4, plate V, was drawn by E. J. Butler.)

THE RELATION OF THE WEATHER TO RUST ON CEREALS.

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THERE are two common views held by practical men in the United Provinces regarding the relation of the weather to rust on the rabi cereals: one is that rust follows on an unusually wet seed-bed, the other that it depends on an abnormal amount of damp cloudy weather in January and February. The appended table has been compiled to test these views; it is drawn up for three districts having observatories where regular weather records are kept, and shows for each district—

(1.) The character of the season as regards rust on cereals;

(2.) The amount of rain in October, which determines the wetness of the seed-bed;

(3.) The average humidity of January and February, and

(4.) The average of January and February taken together.

The character of the season is extracted from the Agricultural Reports: the older reports are at times exceedingly vague, but those from 1892-3 give the facts with sufficient accuracy for the present purpose. The rainfall and humidity figures are drawn from the Monthly Weather Review published by the Meteorological Department. Diagrams are also given which show clearly the fluctuations in average humidity.

The data were originally collected for the decade 1890-1900, but the table has been brought up to 1903 and now shows thirteen years in all.

Taking first the view as to dependence on a wet seed-bed, we get the following facts—

In *Allahabad* the seed-bed was exceptionally wet in

1891-2	...	...	...	No rust.
1893-4	...	...	...	Bad rust.
1894-5	...	...	...	Bad rust.
1897-8	...	...	...	No rust.

while rust followed on a seed-bed not exceptionally wet in 1892-3 and 1900-01. Thus out of four rusty seasons, two had wet seed-beds, and two had not.

In *Jhansi* the only years when the seed-bed was wet were 1893-4 and 1894-5; both were rusty, but there was also rust in 1892-3 and 1900-01, when October was dry.

In *Benares* the seed-bed was wet in

1891-2	...	...	...	No rust.
1893-4	...	...	...	Bad rust.
1894-5	...	...	...	Bad rust.
1897-8	...	...	...	No rust.
1900-1	...	...	...	Bad rust.

while there was rust in 1892-3 with a dry October.

Taking the three districts together, we have eleven wet Octobers with rust following in seven cases.

And we have thirteen rusty seasons out of which seven followed a wet October and six did not.

Turning now to the second hypothesis, we may examine the relation of rust to the average humidity of January and February taken together:—

In *Allahabad* the dampest seasons (in order) were:

Year.		Humidity.	Season.
1900-1	...	83·5	Bad rust.
1894-95	...	82·5	Bad rust.
1893-94	...	80·5	Bad rust.
1892-93	...	79·5	Some rust.
Average.	...	75·0	

That is to say the four years where the humidity was most largely in excess of the average are the four rusty years.

In *Jhansi* the dampest seasons in order were :

1900-01	...	74·5	Bad rust.
1894-95	...	68·0	Bad rust.
1893-94	...	67·0	Bad rust.
1892-93	...	66·5	Some rust.
1902-03			No rust.
Average	...	60·0	

Here again the three dampest seasons are the seasons of worst rust : of the two years that stand fourth on the list there was some rust in one and no appreciable rust in the other.

In *Benares* the dampest seasons (in order) were :

1893-4	...	89·5	Bad rust.
1892-3	...	88·0	Some rust.
1894-5	...	87·5	Bad rust.
1891-2	...	84·5	No rust.
1900-01	...	83·0	Bad rust.
Average	...	80·6	

Here the four rusty years are among the five dampest seasons, but the results agree less closely than in the other cases. The fact that in the dry season, 1899-90, barley rusted badly and wheat escaped is interesting and is not explained by any of the figures I have examined : so far as wheat goes it confirms the other results. Apparently so far as Allahabad and Jhansi go, both January and February must be damp to produce serious results ; or at least this is suggested by the following figures :—

District.	Year.	January.	Febry.	Season.	Remarks.
Allahabad ...	1893-4	80	81	Bad rust ...	Both damp.
	1901-2	83	62	No rust ...	January damp, February dry.
Allahabad ...	1900-1	90	77	Bad rust ...	Both damp.
	1897-8	69	77	No rust ...	January dry, February damp.
Jhansi ...	1893-4	70	64	Bad rust ...	Both damp.
	1890-1	69	50	No rust ...	January damp, February dry.
Jhansi ...	1894-5	76	60	Bad rust ...	Both damp.
	1897-8	45	57	No rust ...	January dry, February rather damp.

Now as the harvest in Benares is distinctly earlier than in either of the other two districts, it seems possible that

there January may be more important than February, in this connection. The dampest Januaries are shown (in order) below :—

1894-5	...	92·0	Bad rust.
1892-3	...	90·0	Some rust.
1893-4	..	89·0	Bad rust.
1900-01	.	88·0	Bad rust.
1891-92	...	87·0	No rust.
Average	...	85·0	

These figures certainly suggest that in those parts of the provinces where the harvest ripens early the humidity of January is the controlling factor, though a comparison of 1892-3 with 1893-4 suggests that the amount of rust is influenced by damp in February also.

To sum up: the following inferences may fairly be drawn for the eastern and southern parts of the provinces (the area where rust causes the greatest loss).

(1) The amount of October rainfall is not a determining factor.

(2) Where the harvest is earliest, the extent of rust varies generally with the humidity of January, though the weather of February is apparently not without some influence.

(3) Elsewhere the extent of rust varies generally with the humidity of the months of January and February taken together.

(4) The case in which barley rusted badly while wheat escaped must have some other explanation.

It will be noticed that what is a damp season in Jhansi would be dry in Benares: it may perhaps be suggested that the fungus is so far adapted to the ordinary weather of *the locality* that its spread is facilitated by excess of humidity over the normal, whether that normal be high or low.

Figures for amount of cloud and proportion of east wind have also been tabulated in the same way: we know in a general way that the dampest seasons usually have the highest amount of cloud and of east wind, and hence there is general

agreement between the curves for the three elements, but it has appeared sufficient for our present purpose to give the figures for humidity only. I understand from a scientific observer (Mr. J. M. Hayman) that both cloud and east wind affect the germination of rust as seen under the microscope; the extent of this effect on the spread of the fungus in the field cannot be determined by an examination of the monthly means, but would have to be determined by comparison of the observed results in germination with the weather conditions prevailing during the day or other short period during which the results were observed.

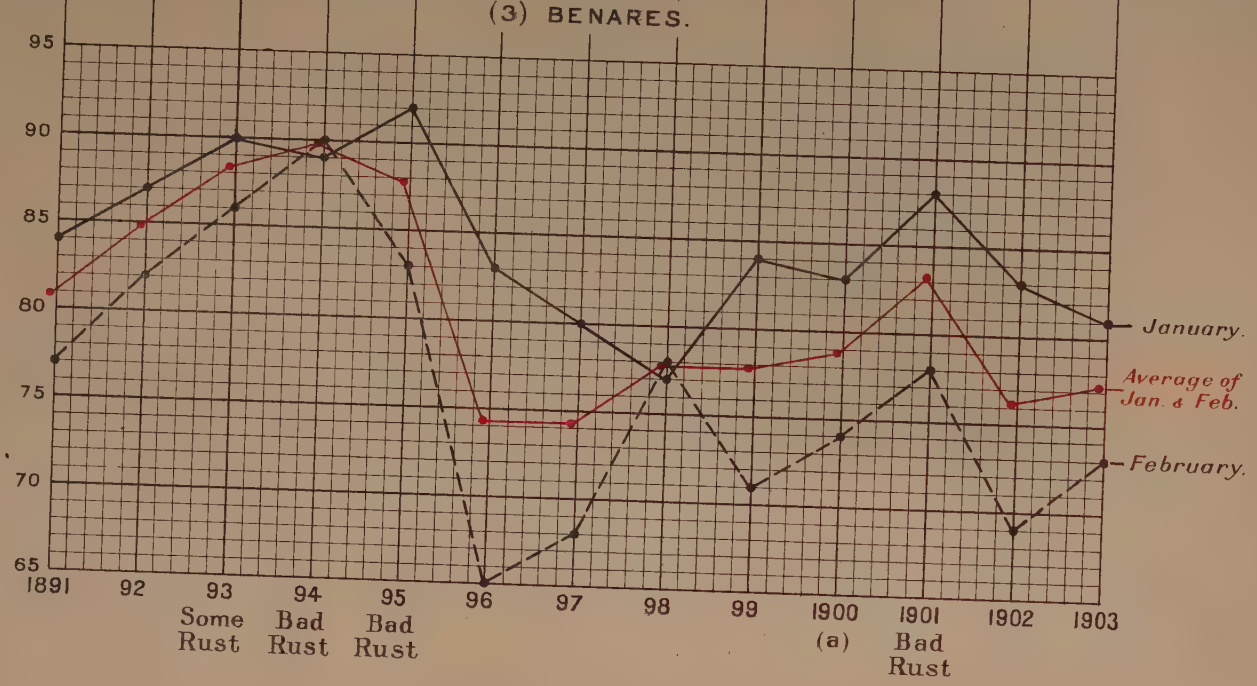
Table showing the relationship between rust and humidity in three districts of the United Provinces.

Allahabad.						Jhansi.						Benares.					
Year.	Season.	October rain. Inches.	Humidity.			Season.	October rain. Inches.	Humidity.			Season.	October rain. Inches.	Humidity.				
			Jany.	Feby.	Average.			Jany.	Feby.	Average.			Jany.	Feby.	Average.		
1890-1	N	1·4	80	69	74·5	N	...	69	50	59·5	N	0·3	84	77	80·5		
1891-2	N	4·2	80	72	76·0	N	...	69	58	63·5	N	2·5	87	82	84·5		
1892-3	S	...	84	75	79·5	S	...	71	62	66·5	S	...	90	86	88·0		
1893-4	B	2·5	80	81	80·5	B	1·8	70	64	67·0	B	3·2	89	90	89·5		
1894-5	B	23·0	88	77	82·5	B	2·4	76*a*	60	68·0	B	11·6	92	83	87·5		
1895-6	N	...	76	55	65·5	N	...	49	43	46·0	N	...	83	65	74·0		
1896-7	N	...	75	55	65·0	N	...	66	45	55·5	N	...	80	68	74·0		
1897-8	N	3·8	69	77	73·0	N	...	45	57	51·0	N	6·5	77	78	77·5		
1898-9	N	...	81	66	73·5	N	...	50	41	45·5	N	...	84	71	77·5		
1899-1900	N	...	83	71	77·0	N	...	53	49	51·0	B*h*	0·2	83	74	78·5		
1900-01	B	0·8	90	77	83·5	B	...	77	72	74·5	B	6·2	88	78	83·0		
1901-02	N	...	83	62	72·5	N	...	69	61	65·0	N	...	83	69	76·0		
1902-03	N	...	79	65	72·0	N	0·2	70	63	66·5	N	...	81	73	77·0		

N=No serious rust.
S=Some rust.
B=Bad rust.
Bh=Bad rust on barley, not on wheat.

a The Weather Review shows 6 only : the figure 76 has been ascertained from the Meteorological Reporter.

HUMIDITY DIAGRAMS FOR JANUARY & FEBRUARY.



(a) *In 1900 there was bad rust on barley but hardly any on wheat*

LITHO; THACKER, SPINK & CO, CALCUTTA.

PLATE I.

1

2

3

4

Black Rust. (Puccinia graminis.)

PLATE II.

YELLOW RUST. (PUCCINIA GLUMARUM.)

PLATE III.

ORANGE RUST. (PUCCINIA TRITICINA.)

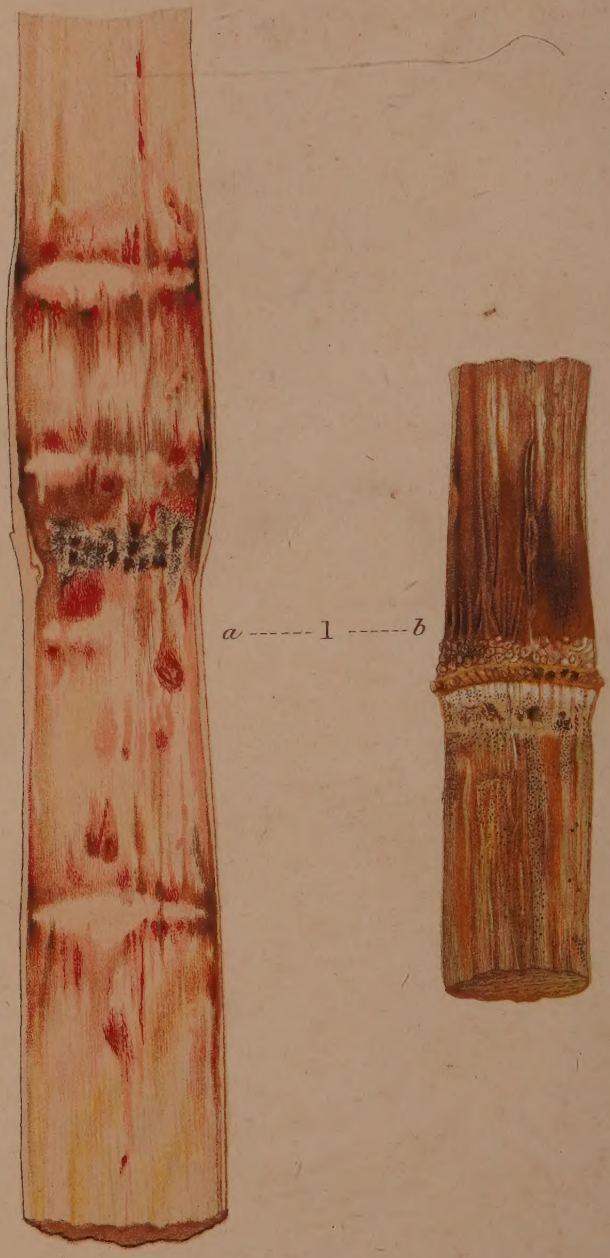
PLATE V.

Figs. 1-2. Æcidium montanum Butl. on Berberis Lycium.

Fig. 3. Æcidium Berberidis Gmel. on Berberis Lycium.

Fig. 4. Infection of Pythium by Chytridiacean Zoospores.

PLATE I.



CHHOTALAL D. SHAH. pinx.

West, Newman chromo.